PHD

Asset Management decision support tools: A conceptual approach for managing their performance

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Asset Management decision support tools: A conceptual approach for managing their performance

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Acknowledgements

In her Reith lecture the double Booker Prize winner, Hilary Mantel, said “history is not the past...it’s what’s left in the sieve when the centuries have run through it”. In the same way this thesis is not presented as a complete diary of my PhD journey. It in no way reflects all the reading, discussions, debates, nor blind alleys that were taken. It is a sanitised representation of my three and a half year academic apprenticeship in which there is no place to convey the personal growth that has taken place, or to acknowledge those who were fundamental in its completion. This is where I try to acknowledge those people.

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Abstract

Decision Support Tools (DSTs) are commonly utilised within the Asset Management (AM) operations of infrastructure organisations. These manual or computerised tools are used to support decisions about what assets to acquire and how to operate them. Their performance can therefore have significant financial and non-financial implications for a business. Despite their importance, managing the performance of DSTs after implementation has received only limited attention within the literature.

The output of this research is a conceptual approach for managing the performance of decision support tools used within an Asset Management context. It encompasses a risk-based DST Performance Management Process and DST Performance Assessment Techniques (the methods for applying the process in an industry setting).

The novelty of the approach: (1) Alignment with the fundamental principles of the International Standard for Asset Management, ISO 5500x:2014. Thus, consistency of the management of DSTs with other assets types. (2) A generic process that is tailored to the context of the specific organisation. (3) Consistency with the risk management process (ISO 31000:2009) and meeting the requirements for a quality process defined within the Quality Management Standard (ISO 9000: 2015). (4) A cyclical process design ensuring that the approach, and how the approach is applied within an industry setting, will evolve to reflect the changing environment.

A case study and the input of subject matter experts from within National Grid Electricity Transmission was used to both inform and evaluate the conceptual approach design. A semi-structured interview, with a water sector subject matter expert, assesses the transferability of the approach to a wider Asset Management population.

The results of the evaluation demonstrate the conceptual approach to be both logical and useable in each context. The future research pathway looks to progress the conceptual approach through to industry adoption.

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Abbreviations

AM	Asset Management
BSI	British Standards Institution
Capex	Capital Expenditure
CBA	Cost Benefit Analysis
EPSRC	Engineering and Physical Sciences Research Council
DSS(s)	Decision Support System(s)
DST(s)	Decision Support Tool(s)
HUT	Have You Thought
IAM	Institute of Asset Managers
ISO	International Organization for Standardisation
NG	National Grid
NGET	National Grid Electricity Transmission
NOM	Network Output Measures
OECD	Organisation for Economic Co-operation and Development
Ofgem	Office of Gas and Electricity Markets
Ofwat	The Water Services Regulation Authority
Opex	Operational Expenditure
RAV	Regulated Asset Value
SAM	Strategic Asset Management DST
Totex	Total Expenditure
WLVF	Whole Life Value Framework

List of Publications

LATTANZIO, S., 2017. Make the Right Choice. Asset Magazine. London: Redhouse Lane.

LATTANZIO, S., 2017. Comments and Code. Asset Magazine. London: Redhouse Lane.

LATTANZIO, S., NEWNES, L. B., MCMANUS, M. & DUNKLEY, D. 2016. Life Cycle Decision Support Tools: The Use of Quality Management Techniques in combating 'Performance Decay'. *IDETC.* Charlotte, North Carolina: Amercian Society of Mechnical Engineers.

LATTANZIO, S. 2016. Keeping Your Tools Sharp. Asset Magazine. London: Redhouse Lane.

In Preparation:

LATTANZIO, S., NEWNES, L. B., MCMANUS, M. & DUNKLEY, D. A Conceptual Approach for Managing the Performance of Decision Support Tools Used in Asset Management.

Chapter 1: Introduction

Decision Support Tools (DSTs) are commonly utilised within the Asset Management (AM) operations of infrastructure organisations. These manual or computerised tools are used to support decisions about what assets to acquire and how to manage them. Their performance can therefore have significant financial and non-financial implications for a business. Despite their importance, managing the performance of DSTs after implementation has received only limited attention within the literature. The output of this research is a conceptual approach for managing the performance of decision support tools used within an Asset Management context. This offers a novel, risk-based approach that aligns with the International Standard for Asset Management, ISO 5500x:2014.

Economic growth and improvements in human wellbeing are intrinsically linked to having the right infrastructure. Current projections estimate that worldwide spending on infrastructure will grow from US$4 trillion per year in 2012, to more than US$9 trillion per year by 2025 (PricewaterhouseCoopers LLP and Oxford Economics, 2015).

One suggested method of reducing the financial input required is to increase asset investment productivity. That is, to make the money invested deliver greater returns. By addressing productivity in the areas of selecting, building, operating and managing infrastructure it is estimated that there is the potential to reduce the investment required by US$1 trillion per annum (McKinsey Global Institute, 2013). In pursuit of these savings the infrastructure sector are creating and implementing manual and computer based systems which assist in making decisions around what assets to acquire and how to operate them. Within AM these are commonly known as decision support tools (DSTs).

With these DSTs comes the promise of improved efficiency and effectiveness of decision-making. However, the benefits of introducing new business initiatives can be uncertain. There are examples of initiatives that have performed well – they are considered to have been successful. However, there are also examples that are considered to have been unsuccessful, or where the benefits they return have not been sustained. This is common across both business processes (Hicks and Matthews, 2010, Jisc., 2016, Streit and Pizka, 2011, Studer, 2014, Van Dyk and Pretorius, 2014), and Information Systems (IS) (Alavi and Joachimsthaler, 1992; Finlay and Forghani, 1998; Salazar and Sawyer, 2007; Sauer, 1993; The Standish Group Report, 2015). Despite this recognised challenge, the literature shows only limited consideration given to managing the performance of DSTs after implementation. This is significant as if the performance of DSTs does not sustain this can potentially lead to non-optimal asset decisions, which in turn can affect investment productivity.

In collaboration with the Engineering and Physical Sciences Research Council (EPSRC), and as part of an Industrial Case Award (iCASE), National Grid (NG) have provided financial and non-financial sponsorship to support the creation of an approach through which to manage the performance of DSTs used within AM.

In order to both understand industry's requirements for such an approach and to evaluate its 'success', a case study of National Grid Electricity Transmission (NGET) was used. NGET is the business area within the NG organisation that owns and operates the high-voltage electricity transmission network within England and Wales, and operates, but does not own, the Scottish transmissions network. In this role NGET have responsibility for the construction and management of an extensive and growing, asset portfolio with a Regulated Asset Value (RAV) in excess of £42.6 billion (National Grid, 2017b). The redesigning of the transmission network to support decarbonisation of the economy means that high levels of investment are set to continue with the Office of Gas and Electricity Markets (Ofgem), the UK energy regulator, estimating that £32 billion will need to be invested in UK energy networks between 2010-20. This effectively doubles that spent during the previous 20 years (Ofgem, 2010).

To support optimised asset decision-making NGET make extensive use of DSTs. Currently they operate in excess of 200 manual and computer based decision tools. Amongst these, there are DSTs that have been recognised by NGET as being 'business critical'. For NGET ensuring that these business critical DSTs are fit for purpose is vital.

The output of this research is a conceptual approach for managing the performance of DSTs used within an AM context. It encompasses a risk-based DST Performance Management Process and DST Performance Assessment Techniques (the methods for applying the process in an industry setting). The future research pathway looks to progress the conceptual approach through to industry adoption.

1.1 Thesis Structure

The literature shows there to be a myriad of complementary, and conflicting approaches which can be used to plan the stages of a research project (Blessing and Chakrabarti, 2009; Chakrabarti and Blessing, 2014, 2015).

This research conducted with this PhD utilises the generic, four stage DRM framework proposed by Blessing and Chakrabarti (2009) (Figure 1). Of the approaches that were considered it was judged preferential as it offered a structured, yet flexible approach, which aligned to the scope and purpose of the research.

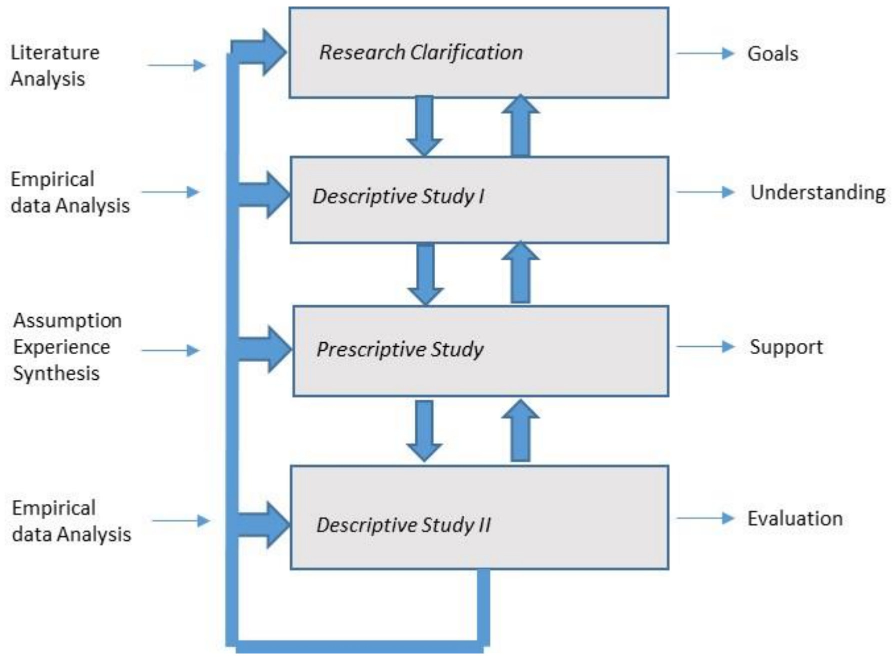


Figure 1. DRM Research Framework (Blessing and Chakrabarti, 2009)

The DRM Framework identifies four research stages:

- ***Research Clarification (Goals)***
  This stage evidences that a realistic and worthwhile research goal exists. Based on the findings an initial description of the current and desired situation is created.
- ***Descriptive Study I (Understanding)***
  Gathers additional information that improves the clarity of the research challenge and informs how it might be addressed.
- ***Prescriptive Study (Support)***
  Understanding gained during the previous two stages is applied in the creation of a 'support' (novel procedure, tool, or technique etc.), which aims to move towards the desired situation.
- ***Descriptive Study II (Evaluation)***
  The impact of the 'support' and its ability to realise the desired situation is evaluated.

Figure 2 shows how the thesis chapters map to the DRM framework.

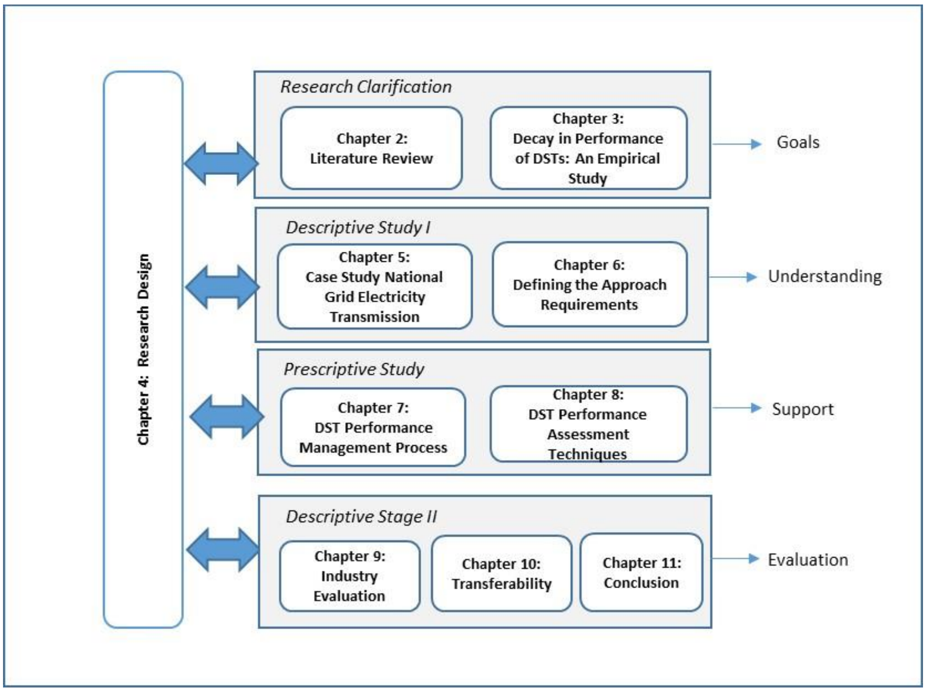


Figure 2. Research thesis structure

The Research Design (**Chapter 4**), details the scientific approach used in conducting this research. For simplicity, the Research Design chapter is depicted as outside, but connected to each of the four stages.

Research Clarification: **Chapter 2** presents an extensive review of the academic and industry literature. The review identifies that DSTs are used to support infrastructure asset decisions. However, although DSTs are being created and implemented limited consideration has been given to their post implementation performance. Specifically, the review was unable to identify any approaches for the performance management of DSTs used within an AM context.

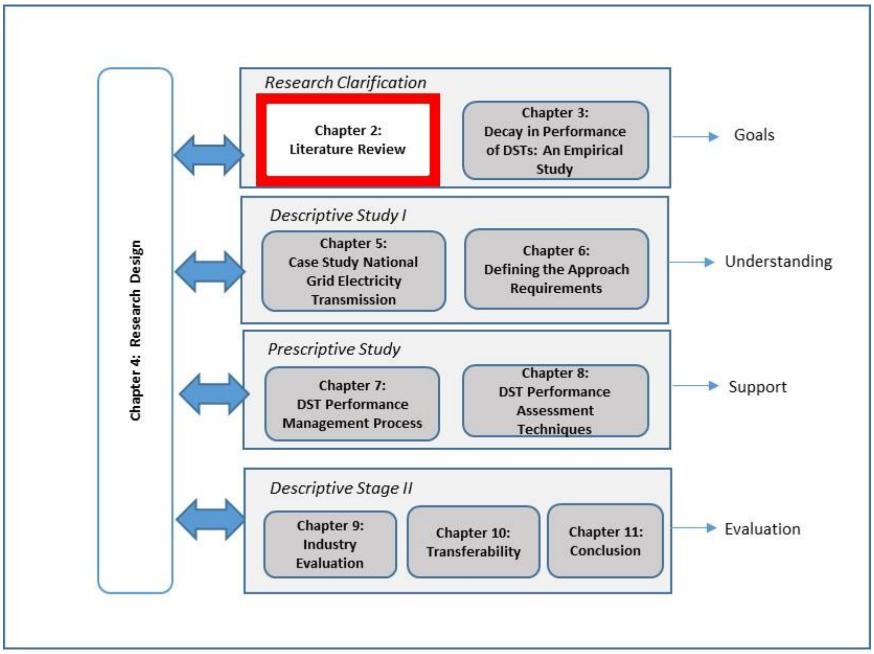
Although the literature review identified a research gap this did not necessarily mean that a research challenge existed. If the performance of DSTs did not change (or if the performance change was always in a positive direction), there may be no industry need for approaches to manage DST performance. **Chapter 3** details an empirical study conducted within this research. It demonstrates that amongst sixteen key UK and international asset owners and international consultancies, working across the water, energy, and transport sectors, there was a perception that DST performance decay does occur.

***Descriptive Study I*:** With the industry need for an approach to manage DST performance confirmed, the research looked to gain further understanding of the context and requirements for such an approach. Within this research a case study of National Grid Electricity Transmission (NGET) was used to both inform, and evaluate the DST performance management approach. **Chapter 5** presents a case study that was undertaken within NGET. It provides an in-depth exploration of DSTs use and governance within the organisation. Following, **Chapter 6** details a study undertaken within NGET that defines the requirements for a DST performance management approach.

Prescriptive Study*:** Understanding gained from conducting this research was applied to the creation of the DST performance management approach. The approach comprises of the DST Performance Management Process ***(Chapter 7), and the DST Performance Assessment Techniques, the methods for applying the process in an industry setting ***(Chapter 8).***

Descriptive Study II*:** To ascertain the 'success' of the approach, an evaluation was conducted with NGET subject matter experts **(Chapter 9).** Following, **Chapter 10** details a study to determine the transferability of the research to a wider AM population. Finally, within the Conclusion ***(Chapter 11), the contribution to knowledge is highlighted, a summary and critical analysis of the research is provided, and future research opportunities are identified.

Chapter 2: Literature Review



The literature review sits within the Research Clarification Stage. It provides the evidence to support that a research challenge exists and gives insights into how it might be addressed. Figure 3 shows the structure of the literature review conducted:

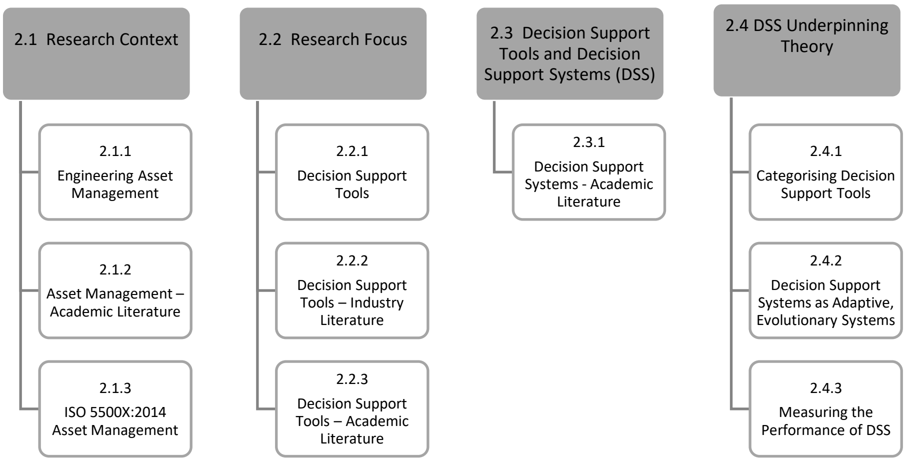


Figure 3. Literature review structure

The review starts by considering the broad research context (2.1). This included defining the term (2.1.1), and reviewing the academic literature relating to Asset Management

(2.1.2). Given the applied nature of the research the Asset Management Standard, ISO 5500x:2014, was reviewed and assessed (2.1.3). This Standard has a particular bearing on how AM is undertaken within industry.

Section (2.2) narrows the literature to that of the research focus - decision support tools (DSTs). The origins of the term are identified (2.2.1), followed by a review of the industry (2.2.2) and academic literature (2.2.3).

Section (2.3) looks for synergies. When reviewing the academic literature it was identified that DSTs are often also identified as Decision Support Systems (DSS). This section considers the DSS literature and seeks to establish the extent of any relationship (2.3.1).

Section 2.3 identified DSS to be a subset of DSTs. Section 2.4 explores underpinning theory within the DSS discipline. This included the different classifications of DSS type (2.4.1), the requirement for decision systems to adapt and evolve (2.4.2), and how DSS performance has been measured (2.4.3)

Following, key concepts from the review are visualised by means of a concept map (2.5), and the research challenge clarified (2.6).

2.1 Research Context

Establishing the setting in which a research project is conducted is vital. It provides the context in which the research is undertaken and helps to identify specifics that may influence or constrain the approach taken.

2.1.1 Engineering Asset Management

Although the practice of *managing assets* has a long history the discipline of *Asset Management* is a relatively new and evolving area (ISO, 2017; Van Der Lei *et al.*, 2012; Zuashkiani *et al.*, 2014). Although sounding similar, within industry the two terms are considered discernibly different.

Managing assets are the things you do to assets. This is done without a structured organisational strategy and context. In contrast, Asset Management has a broader focus encompassing many organisational levels and applying to all functions or departments (ISO, 2017). Table 1, which is taken from a recent ISO publication, show the two terms contrasted across four perspectives.

Table 1. Contrasting Managing Assets and Asset Management (ISO, 2017).

Managing Assets	Asset Management
Your colleagues are focussed on: • Asset data, location and condition • Current KPIs • Department budget	Your colleagues are focussed on: • Information supported decisions (strategic context and related to customer needs) • Strategies to select and exploit assets over their lifecycle to support business aims • Collaboration across departments to optimise resources allocated to activities
Your stakeholders are focussed on: • Costs • Current performance • Response to failure	Your stakeholders are focussed on: • Triple bottom line • Clarity of purpose of the organisation • Focus on impact of activities on organisation's objectives
Your top management is focussed on: • Short term gain / loss • Departmental / individual performance • Savings, especially OPEX	Your top management is focussed on: • Long term value for the organisation • Developing competence and capability across workforce • Business risk understood and mitigated
Your suppliers are focussed on: • Short term contracts and performance • Service level agreements are focussed on contract specifications	Your suppliers are focussed on: • Long term contracts and/or partnering relationships in support of client value and objectives. • Understanding client strategy and needs in 5-10 years.

The information contained within Table 1 shows that whereas managing assets is reductionist and short term in its thinking, AM is holistic, focussing on the long term value that assets contribute towards achieving organisational objectives. This requires taking a life cycle approach to assets and collaborative working across organisational functions.

2.1.2 Asset Management – Academic Literature

As previous identified the discipline of *Asset Management* is a relatively new and emerging area. A review of the academic literature supports this view.

Figure 4 shows the results of a literature search across an on-line academic database (Scopus) using the search criteria: "asset management" within the *Article Title* field; an "engineering" *Subject Area*; and unrestricted date range. The search returned ~ 1400 papers with the first paper appearing in 1976. From 1976 – 1997 the number of publications remain low (< 10 papers per year). From 1997 there is a general rise in the number of publications. This increase appears to coincide with the drafting and then publication of the first Asset Management British Standard, PAS 55, in 2004. Since this time the AM discipline has continued to evolve with PAS 55 undergoing revision in 2008, and superseded by an International Standard, ISO 5500x:2014 (BS ISO 55000 Series: 2014).

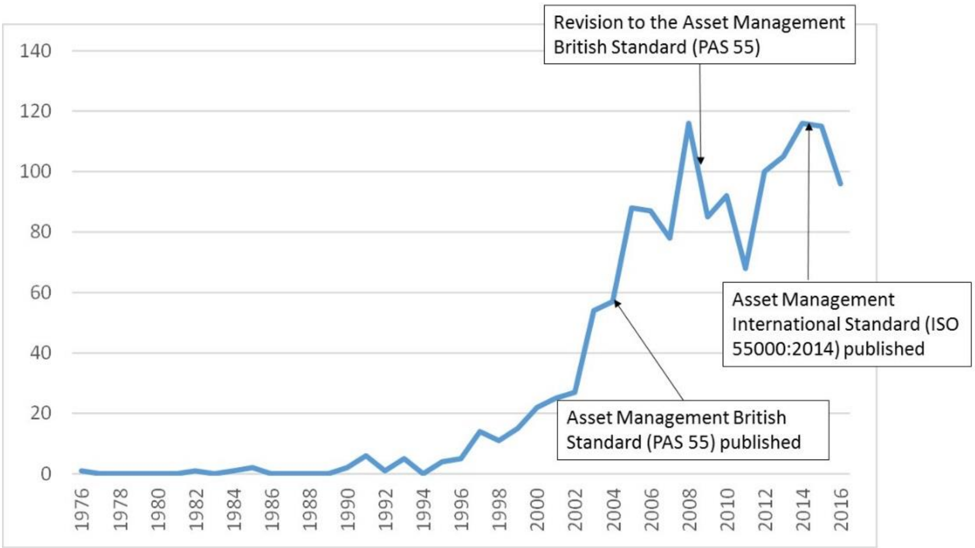


Figure 4. Scopus Publications: "Asset Management" Article title, "Engineering" Subject Area

Although Scopus shows there to be an increasing number of publications it is considered to be an emerging, rather than an established academic field (Zuashkiani *et al.*, 2014). Academic contributions are considered to be at best moderate with the primary contributions to the field coming from government bodies and industrial practitioners (Too, 2010). Consequently, to avoid a narrow perspective both industry and academic literature was incorporated within the review.

Despite a growing body of knowledge there continues to be criticism of AM practice. Business organisations are said to have failed to approach projects in a systematic way with many processes unchanged in decades (McKinsey Global Institute, 2013). The introduction of the International Standard, ISO 5500x:2014 (BS ISO 55000 Series: 2014), works towards addressing these criticisms by the introduction of a recognised global Standard for 'good' AM practice.

2.1.3 Asset Management – ISO 5500x:2014

ISO 5500x (BS ISO 55000 Series: 2014), sets internationally recognised requirements for AM. Within the UK electricity sector certification under the Standard is strongly encouraged by the regulator, Ofgem (Ofgem, 2005). As such, it has a significant bearing on how AM is undertaken in practice.

The current Standard comprises of a suite of three documents:

- BS ISO 55000:2014. Asset Management. Overview, Principles and Terminology

- BS ISO 55001:2014. Asset Management. Management Systems – Requirements
- BS ISO 55002:2014. Asset Management. Management systems – Guidelines for the application of ISO 55001

Replacing PAS 55 in 2014 with the more encompassing International Standard extended the focus of AM from purely physical assets, to anything that has potential or actual value to an organisation (BS ISO 55000 Series: 2014). This increased scope meant that non-physical assets, such as data or software, could be managed within an AM system. Ultimately, which assets are managed is determined by the organisation when setting the scope of their system.

To ensure that the Standard is applicable to a wide range of assets, across a wide range of organisations, it sets **generic**, (rather than specific) requirements for an AM system. Amongst other things it is expected that the AM system should be cross-functional - allowing integration and collaborating across the organisation - and will manage the asset across its life cycle (BS ISO 55000 Series: 2014). Although providing the requirements for an AM system it does not extend to providing techniques, or financial / accounting guidance.

Within the Standard, AM is described as the coordinated activity to realise value from assets (BS ISO 55000 Series: 2014). This value is generally achieved through the balancing of asset cost, risk, opportunity and performance. Within the AM paradigm risks are not avoided but managed; costs are not minimised but optimised; and performance is not maximised but adjusted to achieve thresholds (Varadan, 2013).

The key aspects of an AM system are depicted in Figure 5. Here it is shown that the AM system works within the context of the organisation (BS ISO 55000 Series: 2014). Organisational plans and objectives directly link to the asset management plan, objectives, and policy. That is, AM plans are developed top-down with the aim of assisting towards the organisation achieving its objectives. Elements outside of the core AM documents support delivery of the AM plan. Feedback loops exist within the system and provide ‘learning’ both for the AM system and the wider organisation.

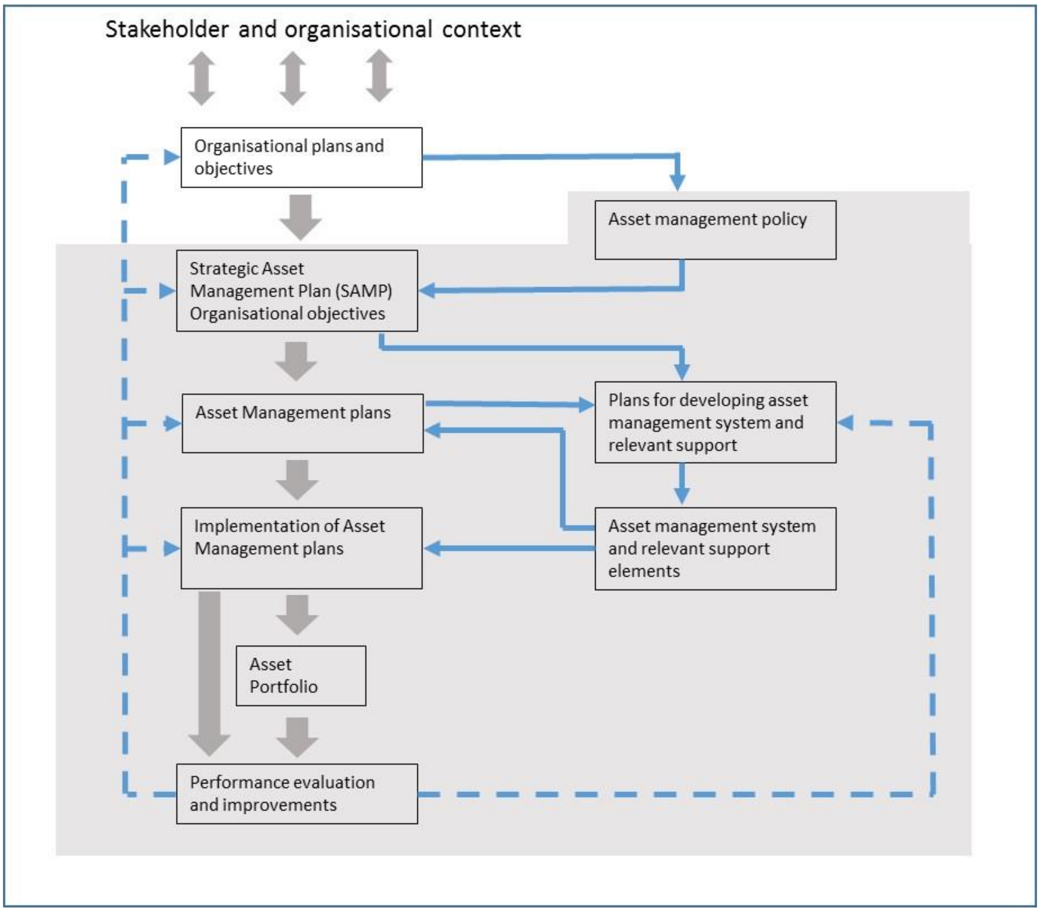


Figure 5. Key elements of an asset management system (BS ISO 55000 Series: 2014)

Figure 5 highlights the interconnected nature of AM. Changes in organisational objectives, or stakeholder requirements, can necessitate the alteration of AM plans. Ultimately, a change in organisational objectives can have repercussions for what would be the optimal asset acquisition and management choice. For example, if the organisation introduced an objective to reduce its CO_2 emissions, this would be reflected within the AM asset plans and ultimately in the asset choices which are made.

2.2 Research Focus

The overarching focus of the research was decision support tools (DSTs) used within AM. This section presents an overview of the industry and academic literature in this area.

2.2.1 Decision Support Tools

As previously stated ISO 5500x:2014 is the International Standard for AM. Within the Standard's suite of documents there is no use of the term *decision support tool,* or the truncated *decision support*. Consequently, it provides no insight into what a DST might be, or do.

Although there is no mention of DSTs, there is reference to decision making and having criteria for decision making (BS ISO 55000 Series: 2014). A requirement within the Standard is that the organisation should determine and document the method and criteria for decision making. In accordance with the purpose of the Standard to set the requirements for a management system, rather than provide technical advice on how AM activities should be conducted, it does not provide further guidance or propose any techniques which might be used.

With the Asset Management Standard not making reference to DSTs it raises the question of from where the term originates. Perhaps the most significant use of the term DST is within the IAM publication, Asset Management – an Anatomy (IAM, 2014). The stated purpose of the Anatomy is to provide a platform for common language and describe the principles of Asset Management. It is amongst the documents on which the IAM professional examinations are based. Consequently, within AM practice, *decision support tools* is a recognised terminology and is seen within articles, job adverts, and in the course content offered by accredited IAM training providers (IAM, 2016c).

Despite the term appearing within the IAM publication there is no attempt to formally define the term; or indeed the rules for what would, or would not be considered a decision support tool. The extent of the reference made to DSTs is that they are used in strategic planning activities, and can include investment modelling systems. Thus, they can be consider to be support elements within an AM system.

Although, it was established that DSTs operate within AM, neither the ISO AM Standard, or the Anatomy provided specific examples. A review of the literature sought to identify examples of DSTs used within industry.

2.2.2 Asset Management Decision Support Tools – Industry Literature

With the term DST being commonly used within AM professional practice it was expected that there would be industry examples which could be examined. However, access to the detail of DSTs used within industry was problematic both in terms of identification and the level of detail available. The IAM however did provide useful and up to date insight within their publication, Asset Management Decision Making (IAM, 2015).

Within this publication it is stated that the DST should be proportional to the criticality and complexity of the problem. The matrix they provide (Figure 6) shows that as the criticality and complexity of the problem increases, the DST strategy will change. In their most basic form DSTs are used to solve problems using simple, structured common sense;

whilst at their most complex they employ customised system/programme simulations. DSTs can therefore be seen to encompass both manual and computer based tools.

<table>
<tr><td></td><td colspan="5">Increasing Complexity of the Decision →</td></tr>
<tr><td rowspan="5">↑
Criticality / size of the decision</td><td></td><td>Yes / No decisions</td><td>Options or scenario choices</td><td>Specific task evaluation & timing optimisation</td><td>Multiple tasks or systems configuration optimisation</td></tr>
<tr><td>Customised system / programme Simulation</td><td>n/a</td><td>5</td><td>n/a</td><td>5</td></tr>
<tr><td>Quantified cost / benefit / risk calculation</td><td colspan="2">3</td><td colspan="2">4</td></tr>
<tr><td>Rules, templates & decision trees</td><td></td><td colspan="2">2</td><td>n/a</td></tr>
<tr><td>Simple, structured common sense</td><td colspan="3">1</td><td>n/a</td></tr>
</table>

Figure 6. Decision strategies (IAM, 2015)

Within the publication ten case studies of DSTs used within industry are presented. All of the examples are from infrastructure organisations whose core business is based on the effective use of assets including: National Grid, Network Rail, and London Underground. The analysis showed the use of manual, computer based databases and spreadsheets utilising standard computer software (i.e. Excel), and customised software system solutions. It also showed variety both in the decision problems they support and the attributes and strategies they use (Table 2).

The ten case studies provide real examples of how DSTs are being used across the UK water, energy, and transport sectors. DSTs are shown to address a range of asset decision problems including what assets to buy (case studies G & H), and how to manage them (A-J). Two of the organisations (National Grid and the London Underground) are seen to operate more than one DST suggesting the use of multiple DSTs to address the different asset decisions problems of an organisation.

Table 2. Decision Support Tools used in Asset Management (IAM, 2015)

Organisation	Severn Trent	Sasol	National Grid		Electricity North West	Citipower	Network Rail	London Underground		Sellafield
Sector	Waste Water	Oil & Gas	Electricity		Electricity	Electricity	Rail	Rail		Nuclear
Case Study Reference	A	B	C	D	E	F	G	H	I	J
Lifecycle Costing	✓		✓			✓	✓	✓	✓	
Value Optimization		✓		✓	✓			✓		✓
Quantifying Risk			✓	✓		✓	✓		✓	✓
Value Opportunities		✓		✓	✓	✓				
Short-term benefits		✓					✓		✓	
Long-term benefits		✓	✓		✓		✓		✓	
Decision-making tools		✓	✓	✓	✓	✓	✓	✓	✓	
Communication with stakeholders					✓					✓
Corporate data		✓		✓		✓				
Create / acquire							✓	✓		
Utilize							✓			
Maintain							✓			✓
Modify / Improve						✓	✓	✓	✓	✓
Renewal / Dispose		✓	✓			✓	✓	✓	✓	
Performance / Reliability	✓		✓	✓			✓	✓	✓	
Life Cycle Activities		✓			✓	✓		✓	✓	
Auditable		✓	✓	✓						
Regulation	✓		✓			✓				
Business Planning	✓		✓	✓	✓	✓	✓	✓	✓	✓
Condition Assessment	✓		✓	✓		✓	✓	✓	✓	
Optimisation	✓	✓	✓	✓		✓	✓	✓	✓	
Life Extension				✓				✓		
Intangible Benefits		✓			✓			✓		

Although holding the promise of improved efficiency and effectiveness of decision making there was no evidence of how the performance of these tools sustained over time. The primary focus of the ten case studies was to present the DST approach. Specifically, there was no reference to how the performance of the DST was managed during its operational life. That is, how the performance of the DST was measured, monitored, analysed and evaluated after implementation. This is significant as the literature shows that there is a challenge in sustaining performance which is common across both business processes (Hicks and Matthews, 2010, Jisc., 2016, Streit and Pizka, 2011, Studer, 2014, Van Dyk and Pretorius, 2014), and Information Systems (IS) (Alavi and Joachimsthaler, 1992; Finlay and Forghani, 1998; Salazar and Sawyer, 2007; Sauer, 1993; The Standish Group Report, 2015). If DSTs do experience a decline in performance, this may influence the efficiency and effectiveness of the decisions made, and ultimately may affect investment productivity.

Although the IAM document provided some insight into what was happening in industry, academia and industry do not necessarily mirror each other. The next stage was to compare and contrast findings with the academic in the area.

2.2.3 Asset Management Decision Support Tools – Academic Literature

To identify the academic literature a search of the academic databases (1) Scopus (all subjects) (2) Web of Science (WoS) (all subjects), (3) Compendum via Engineering Village (interdisciplinary engineering) was conducted. The search used the term "decision support tool*" appearing within the article title, abstract, or key words. Figure 7 compares the results of the three searches by publication year.

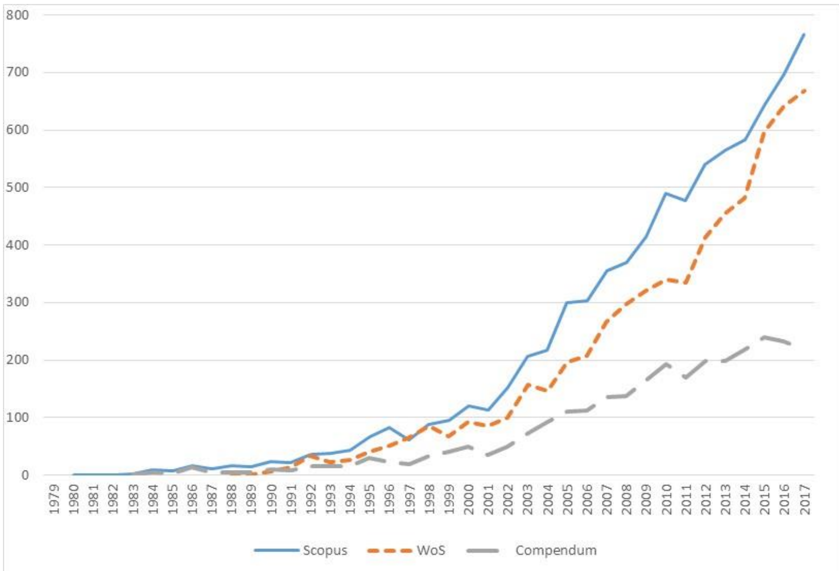


Figure 7. Publications: "decision support tool" within the article title*

Across all three databases the term decision support tool(s) is seen to emerge in the early 1980s. Subsequently, a general annual increase in publications is seen. A preliminary analysis showed DSTs being used to address all manner of problems, in all manner of sectors, using all manner of strategies.

Although this was evidence of the term being used generally, the focus of this research was DSTs used in Asset Management. A search was conducted using the terms “asset management” AND “decision support tool*” appearing within the article title, abstract or key word field, and with an unrestricted date range. The search returned just 69 papers (Scopus), 33 papers (WoS), and 27 papers (Compendum). These show that the term first appears in 1991 (1 paper) but then does not appear again until the early 2000s. Analysis of the Scopus papers (the largest data source), showed that from 2014 there is an increase in papers, rising from an average of less than three papers per year (2001-2013), to around nine (2014-2016). Therefore, although papers are being produced, academic publications which specifically identify as DSTs used in Asset Management remain low.

Refining the search terms to “asset management” AND “decision support tool*” AND “infrastructure” reduced the total number of papers identified to 30. Excluding those papers which were either of a general nature or outside of scope (i.e. excluding environmental assets), resulted in 25 papers. An overview of these papers (sector and description) is shown in Table 3.

Similar to the industry literature the DSTs were seen to be used across a range of infrastructure sectors, and to address a range of decision problems. These could be broadly grouped into those where the focus of the problem was operational – affecting exisiting components and systems i.e. maintenance (e.g. Dunn and Harwood, 2015), or system optimisiation (e.g. Rahmawati et al., 2012); and those which were concerned with investment i.e. representation models which support decisions about future spending (e.g. Bhamidipati, 2015). As seen within the industry literature the focus of the papers was on presenting an approach with little consideration given to management of operational performance. Unlike the industry literature, where the DSTs included a spread of both manual and computer based systems, the primary focus of the academic papers was computer-based approaches.

Table 3. Literature review. Decision Support Tools used in infrastructure Asset Management

Reference (date order)	Sector	Description
Reed (1991)	Transport	GIS-based pavement management information system
Vanier (2001)	Facilities	Municipal infrastructure planning
Hajek *et al.* (2004)	Transport	Maintenance and rehabilitation planning
Grussing *et al.* (2006)	Facilities	Optimising maintenance / renewal of buildings
Alegre *et al.* (2007)	Water	Prioritization of water distribution system investments
Salem *et al.* (2010)	Transport	Identify the most preferred repair/ renewal procedures for culverts
Michele and Daniela (2011)	Mixed	Life-cycle management system
Mills *et al.* (2011)	Transport	Whole-life, whole system costs associated with the vehicle track interface
Ismail *et al.* (2011)	Transport	Model to rank road condition based on several performance indicators (KPI)using a probabilistic framework
Rahmawati *et al.* (2012)	Energy	Integrated modelling and optimization within the oil industry
Large *et al.* (2014)	Water	Predict structural deterioration of water infrastructure
Rehan *et al.* (2014)	Water	Financially sustainable management of wastewater collection works
Sousa *et al.* (2014)	Water	AI tools for assisting the planning of operation and maintenance activities of wastewater infrastructures
Mikhaylov *et al.* (2015)	-	Lifecycle planning, works prioritisation and calculate asset value to meet financial reporting obligations
Marzouk and Osama (2015)	Mixed	Replacement of infrastructure assets in mixed infrastructure system
Hesketh *et al.* (2015)	Transport	Investment planning and prioritisation of maintenance spending
Bhamidipati (2015)	Transport	Long term strategic planning
Dunn and Harwood (2015)	Transport	Maintenance of bridges
Marlow *et al.* (2015)	Water	Cast iron pipe rehabilitation
Ng *et al.* (2016)	Facilities	Reduce the lifecycle and social costs and improve the transparency of public housing programs
Irfan *et al.* (2016)	Transport	Maintenance and rehabilitation of pavements
Power *et al.* (2016)	Transport	Risk-based prioritisation matrix for earthwork assets within the rail sector
Elsawah *et al.* (2016)	Water	Risk-based planning for rehabilitation of water and sewer networks
Monteiro *et al.* (2016)	Water	Financial sustainability of water and sanitation services in developing countries
Sinha *et al.* (2016)	Water	Analysis, simulation, visualisation and evaluation of the behaviour of pipeline infrastructure

2.3 Decision Support Tools and Decision Support Systems

As identified (2.2.1) the term DST is commonly used within AM practice. Here DST are seen to be manual, computer based databases / spreadsheets, and customised computerised systems which aim to support a range of decision problems (2.2.2 & 2.2.3). Although the term is found within the academic literature it is not an established academic research area. As such, there is limited underpinning academic theory on which to build future research efforts.

Decisions Support Systems (DSS) are computer based solutions to solve decision problems. Unlike DST, DSS are a recognised academic discipline being taught in higher education, and with a number of academic journals e.g. Decision Support Systems, Journal for the Association for Information Systems, and MIS Quarterly. Consequently, if a relationship exisits between DST and DSS there was a body of knowledge which could be used to shape and underpin the research going forward. The review therefore sought to ascertain if such a relationship exisited.

2.3.1 Decision Support Systems – Academic Literature

DSS have been described as "interactive **computer based systems** which help utilize data and models to solve unstructured problems" (Sprague, 1980) "**information systems** designed to **help** managers solve problems in relatively unstructured decision-making environments" (Meador and Keen, 1984), and "**computer-based** information systems that are designed with the purpose of **improving** the process and outcome of decision making" (Briggs and Arnott, 2004). Perhaps the most all-embracing attempt to decribe the term is provided by the website DSSResources.com (Power, 1995). Here a DSS is defined as:

- An interactive **computer-based** system or subsystem intended to **help** decision makers use communications technologies, data, documents, knowledge and/or models to identify and solve problems, complete decision process tasks, and make decisions.
- A general term for any computer application that **enhances** a person or group's ability to make decisions.
- An academic field of research that involves designing and studying Decision Support Systems in their context of use.

Given this broad definition DSS can be seen as a subset of DST; that is, computer based DSTs could be considered to be DSS. Although manual DST would not fall within the general definition of a DSS, their fundamental purpose is the same. Indeed, when making a decision about whether to computerise a manual decision system it is seen by some not to be a question of whether it is possible, but rather whether the benefit of computerisation outweighs the costs that would be incurred (Marsden and Pingry, 1993).

The relationship between DSS and DST is supported within the literature. A search of the literature on Scopus showed that of 7452 papers which used the term DST, 4889 (~65%) also used the term DSS within their keywords. Figure 8 visualises the two datasets - (1) papers identifying as DST (2), papers identifying as DST also using DSS within their key words.

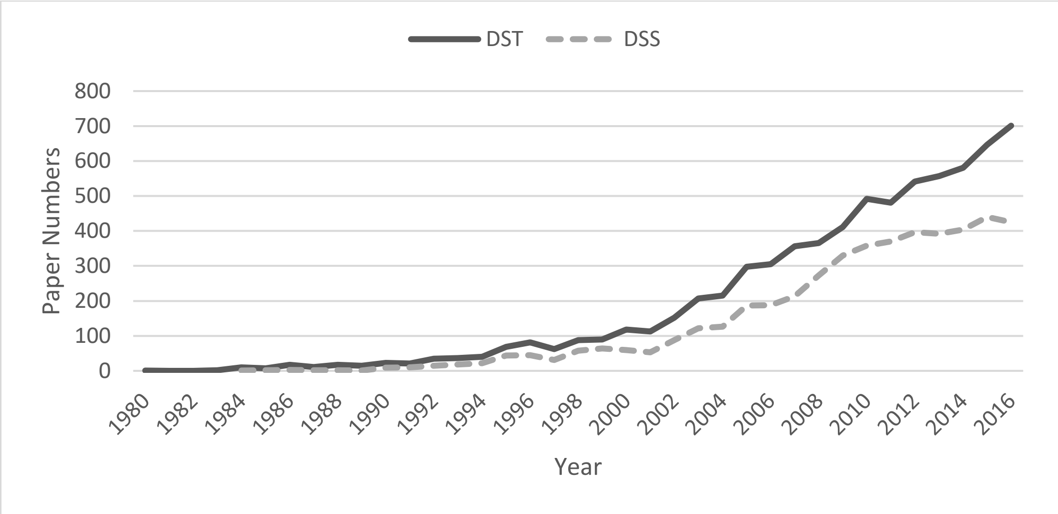


Figure 8. Scopus publications: DSTs also identifying as Decision Support Systems

The same relationship was seen to be true of DSTs used in AM. Twenty one of the 25 papers idenitified in Table 3 using the term “decision support system*” within the *Key Words* which describe the content of the paper.

2.4 Decision Support System - Underpinning Theory

The literature identifed that DSSs can be considered to be a subset of DSTs. The review therefore looked to identify underpinning theory in this area.

Asset Management is intended to operate across organisational functions (BS ISO 55000 Series: 2014). The literature showed DSTs to be without definitive definition, demonstrating variety in both the problems they address and the strategies they used (2.2.2 & 2.2.3). This variety was a potential barrier to effective communication both within and across organisations. With the DSS academic community taxonomies and classification schemes have been developed which work towards creating a common understanding.

2.4.1 Categorising Decision Support Systems

Creating taxonomies, and typologies help people organise and categorise information (Power, 2002). They are considered crucial in understanding new or complex subjects (Sprague and Watson, 1996). Since the emergence of the term a number of authors have attempted to create means through which to categorise DSS.

Perhaps the earliest attempt at DSS classification can be seen in the work of Alter (1977). He identified that computerised DSS are not homogeneous - variation could be seen in what they did, and how they did it. He argued that DSS could be categorised by the generic operation they perform, independent of the problem it sought to solve, or the area in which it was operated etc. His work identifed seven distinct types of decision support systems (Table 4). These types demonstrated a range from extremely data oriented, to extremely model oriented. Over the four decades since it's creation Alter's taxonomy has been widely used and reattested. Whilst some have supported its use (Pearson and Shim, 1994), and used it as the basis for the creation of new DSS lineage frameworks (Arnott, 2004); others have found a broader framework necessary (Power, 2002).

Table 4. Taxonomy of Decision Support Systems (Alter, 1977)

Taxa	Description
File Drawer System	Allow immediate access to data items
Data Analysis Systems	Allow manipulation of data by tailored or general operators
Analysis Information Systems	Provide access to a series of databases and small models
Accounting Models	Calculate the consequences of planned actions using accounting definitions
Representational Models	Estimate the consequences of actions without using or partially using accounting definitions
Optimisation Models	Provide guidelines for action by generating an optimal solution
Suggestion Models	Provide processing support for a suggested decision for a relatively structured task

Over time, a number of alternate methods of classification have been proposed including: scope (Donovan and Madnick, 1977); user relationship (Haettenschwiler, 1977), task dependency (Hackathorn and Keen, 1981); mode of assistance (Power, 2002); and type (Arnott and Pervan, 2014) (Table 5).

Table 5. Decision Support System Classification Models

Reference	Classification	Categories	Description
Donovan and Madnick (1977)	*Scope*	Institutional Ad Hoc	Decisions of a recurring nature Specific problems that are usually not anticipated or recurring
Haettenschwiler (1977)	*User Relationship*	Passive Active Cooperative	Aiding without providing explicit decision suggestion or solutions Providing solutions or decision suggestions Consolidated solution through a process of interactive refinement of between DSS and its user
Hackathorn and Keen (1981)	*Task Dependency*	Personal DSS Group DSS Organisational	Discrete decision relatively independent of other tasks Group of individuals undertaking seperate but highly inter-related tasks Activity involving asequence of operations and actors
Power (2002)	*Mode of Assistance*	Communication Data-driven/data-oriented Document-driven Knowledge-driven Model-driven	Supporting more than one person working on a shared task Access to and manipulation of company internal/external data Managing, retrieving and manipulating unstructured information), Specialized problem-solving based on expertise stored as facts, rules, procedures or similar structures Access to and manipulation of a statistical, financial, optimization or simulation model
Arnott and Pervan (2014)	Type	Personal Decision Support Systems Business Intelligence Group Support Systems Negotiation Support Systems Intelligent Decision Support Systems Knowledge Management Systems	Small scale systems that are developed for one manager or a small number of independent managers, to support a decision task Large-scale systems that use data and analytics to support decision making at all levels of an organization. BI systems are often based on a data ware- house or data mart The use of a combination of communication and DSS technologies to facilitate the effective working of groups DSS where the primary focus of the group work is negotiation between opposing parties The application of artificial intelligence techniques to decision support Systems that support decision making by aiding knowledge storage, retrieval, transfer, and application by supporting individual and organizational memory and inter-group knowledge access

Whilst these typologies provide general groupings, other authors have looked at more technical classifications schemes for example, user interfaces, and software (Packalen *et* *al.*, 2013), and multi-criteria approach taken (Kabir *et al.*, 2013). These typologies demonstrate the wide range of DSS, and categories through which they might be grouped. The challenge in selecting a typology is to identify which of the suggested models best suits the purpose for which it is intended.

Although the classifications show there to be a range of DSS there is seen to be a common guiding principle in their design and management. DSS should be adaptive, evolutionary systems.

2.4.2 Decision Systems - Adaption and Evolution

That a DSS should evolve through an interative process of design and use has been central to theory and practice in this field (Arnott, 2004; Courbon, 1996; Keen, 1980; Sprague, 1980). Dynamic cognitive and environmental factors mean that the system can never be final; it must be flexible and adapt frequently to track the changes in the problem, user, and environment (Courbon, 1996).

Change in DSS types, created through the emergence of new technology, is clearly demonstrated within the literature (Arnott and Pervan, 2005, 2014). The geneology of the DSS field shows how over the period from 1960 – 2010 the types of DSS and their theoretical foundations have developed (Figure 9).

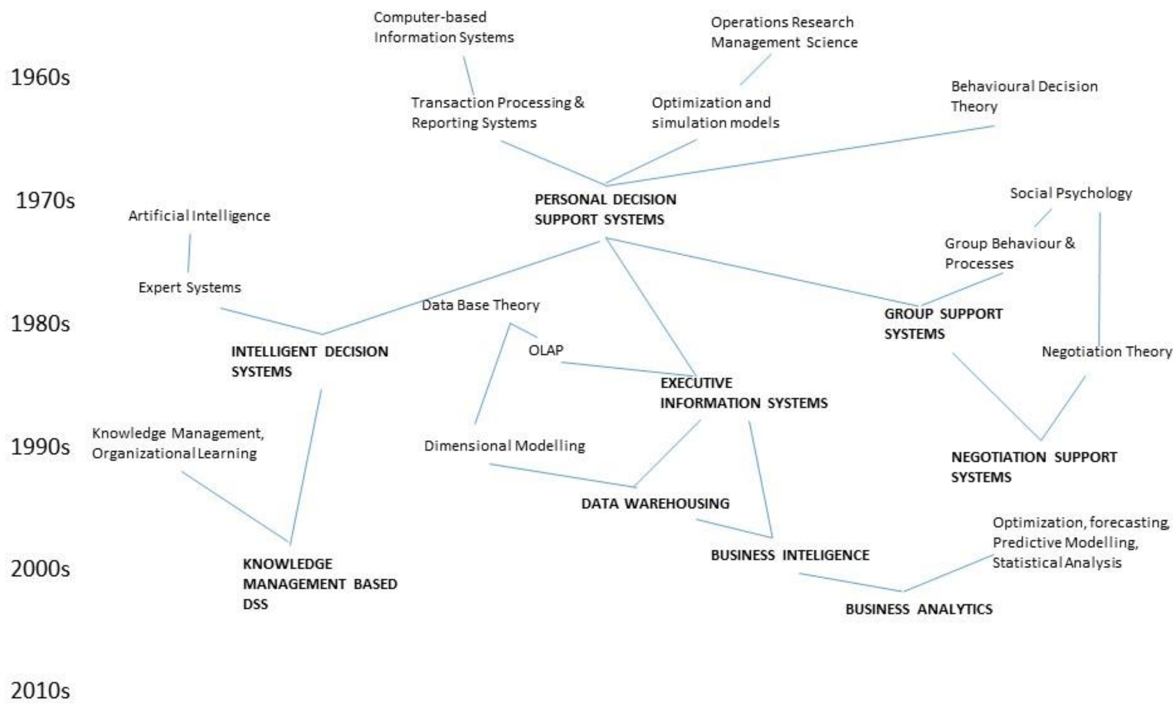


Figure 9. Genealogy of DSS field 1960- 2010 (Arnott and Pervan, 2014)

However, Sprague (1980) argues that emerging technology is not the only change which should be accounted for and that DSS require 'flexbility' across three timeframes. In the short term a DSS should provide the 'user' with the freedom to explore a problem; to solve the problem in a personal way.   In the intermediate time the DSS must respond to changes in the environment and user's behaviour; it is adapted within the constraints imposed by the existing system. In the long term the DSS should incorporate technology change into the system.

Keen (1980) supports the requirement for DSS to be adaptive and goes so far as saying that if a DSS is not learning, evolving, and adapting, it should not be called a DSS. His work, which is the most cited and as such arguably the most influential work on the subject, proposes a model of DSS change which identifies three actors (user, system, and builder). These actors are linked and influence each other in complex ways. The model is shown in Figure 10 with the arrows representing the direction of influence.

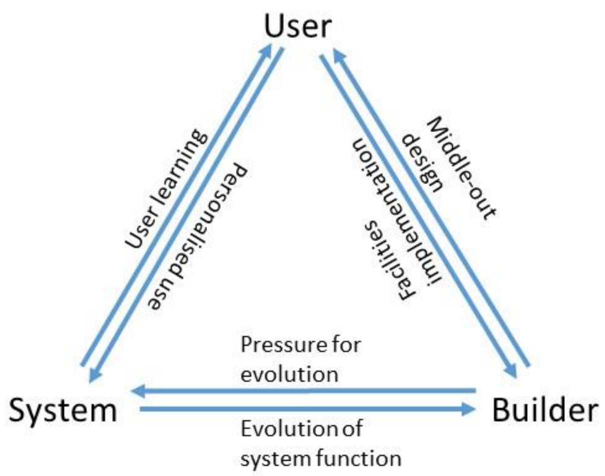


Figure 10. An adaptive framework for DSS (Keen, 1980)

Courbon (1996) describes the sequence of DSS change as action/reflection. That is, a change to the DSS is made (action), the user then works with the new system and feeds back to the systems analyst (reflection). Together they decide the next course of action.

The works of Sprague (1980), Keen (1980), and Courbon (1996) are important as they not only highlight the evolutionary nature of DSS, they demonstrate that to achieve DSS evolution will involve different roles and skill sets which transend organisational department boundaries. As in Asset Management it will require cross-functional working and clear communication.

Although it is recognised that adaption of computer systems is not a new requirement, for DSS change will be quicker, requiring new approaches to be taken both within development stage and in the traditional view of the systems life cycle (Courbon, 1996; Sprague, 1980). Research conducted by Benamati and Lederer (2008) aimed to identify the challenges of rapid change. The problems identified encompassed quality issues, management confusion, incompatiaility across systems, and a requirement for additional training. The conclusion of 16 indepth interviews and 246 surveys of IT practioneers, was that successful decision support systems depends on having a system in place which gathers, stores and provides appropriate information.

These seminal works by Spargue, Keen, and Courbon have been built on and expanded by numerous others; an overview of selected contributions from the period 1983 - 2011 are shown in table 6.

Table 6. Selected contributions to DSS evolution theory. Adapted from Arnott (2004)

Reference	**Contribution**
Keen and Gambino (1983)	DSS adaption occurs at the sub-task rather than the task level. This is a driver of system evolution
Stabell (1983)	DSS evolution should take place in a tension between the descriptive and prescriptive views of the target decision
Alavi (1984)	DSS prototyping yields higher utilisation of systems as well as better designer and user attitudes towards the design process
Young (1989)	Developed a three-stage DSS methodology whose final stage is iterative use, refinement, and assessment
Arinze (1991)	DSS methodologies are a tool for reducing the 'unstructuredness' of managerial decision-making
Sage (1991)	Developed a seven stage iterative DSS design methodology. Information requirements determination exists in all stages of the DSS development process and is the likely driver of evolution
Shakun (1991)	Use of evolutionary development theory in group decision support systems
Silver (1991)	Extended evolutionary theory by considering how DSS restrict or limit decision-making processes and how DSS can guide or direct a user's approach to the operation of a system
Suvachittanont *et al.* (1994)	Extended Keen's adaptive design model to executive information systems
O'Donnell *et al.* (2002)	Identified evolutionary development in commercial data warehousing methodologies
Arnott (2004)	Builds on previous research to create a framework of DSS evolution
Esposito *et al.* (2011)	Uses evolutionary development in clinical health DSS

That evolution is central to the design of a DSS suggests that if they did not evolve then their performance would decline. Indeed, it is one of the stated Laws of Software Evolution that unless an evolutionary system is continually adapted it becomes progressively less satisfactory in use (Herraiz *et al.*, 2013; Lehman, 1980; Lehman *et al.*, 1997). Given that it is possible for effectiveness to change, the review looked to consider how measuring the performance of DSS has been addressed within the literature.

2.4.3 Measuring the Performance of DSS

The literature shows that a number of methods have been applied to measure the performance of DSS. An early study by Cats-Baril and Huber (1987) considered the performance of different types of career planning decision systems. The six dependent variables used in measuring effectiveness were:

1. Quality of user performance: subjectively assessed by a subject matter expert.
2. User productivity of ideas: objective quantative analysis.
3. User confidence with the quality of their performance: participant survey.
4. User satisfaction with the decision system: participant survey.
5. Changes in user attitude towards the problem addressed: participant survey
6. Changes in the user attitude towards computers: participant survey.

Therefore, within this research, performance was assessed against multiple concepts comprising of both subjective and objective measures, and integrating both net benefit with user experience.

Work by Barr and Sharda (1997) looked to consider whether the use of DSS resulted in higher quality decisions. Their research used a design whereby DSS were either introduced, or removed from the financial planning decision process. Unlike the multiple performance criteria used by Cats-Baril and Huber (1987), effectiveness was based purely on financial "bottom line" performance.

The use of different categories and metrics when measuring IS (information system) performance was identified in the work of DeLone and McLean. Indeed, they claim that that in measuring IS performance there were almost as many variables used as there were studies undertaken (DeLone and McLean, 1992). To address this disorder Delone and McLean set about creating a taxonomy, and developing these categories into a model for measuring IS success. The revised model, presented in 2003, comprised of six interconnected categories (information quality, system quality, service quality, intention to use/use, user satisfaction, and net benefits), which all contribute towards the overall 'success' of the system (DeLone and McLean, 2003).

Although the Delone and McLean approach has been widely used and empirically validated across multiple IS types (Petter and McLean, 2009), Ben-Zvi (2012) identify that when measuring the effectiveness of a DSS very few studies have incorporated process variables such as user attitude. The reasons they suggest for their ommission include that process variables may be considered less important, they are difficult to capture, or that they these measures did not align with the research goal.

The literature showed there to be inconsistency in the way that DSS performance is measured within the literature. Moreover, it did not offer a practical approach which could be applied to manage the performance of DST used within an AM context. That is, were there are multiple types of DSTs, use to addressed a rnage of decisions problems, and where harmonisation and integration with the ISO AM Standard is vital.

2.5 Key Concepts

Although presenting the findings of a literature review in a text format has use, it is difficult to both uncover and communicate how key concepts across the texts relate (or have been assumed to relate). A concept map is a graphical representation in which information 'nodes' are connected to other related ideas through a series of labelled links (Novak, 2010). Within this research a concept map was created as a means through which to identify and communicate the relationships between the key information within the literature (Figure 11).

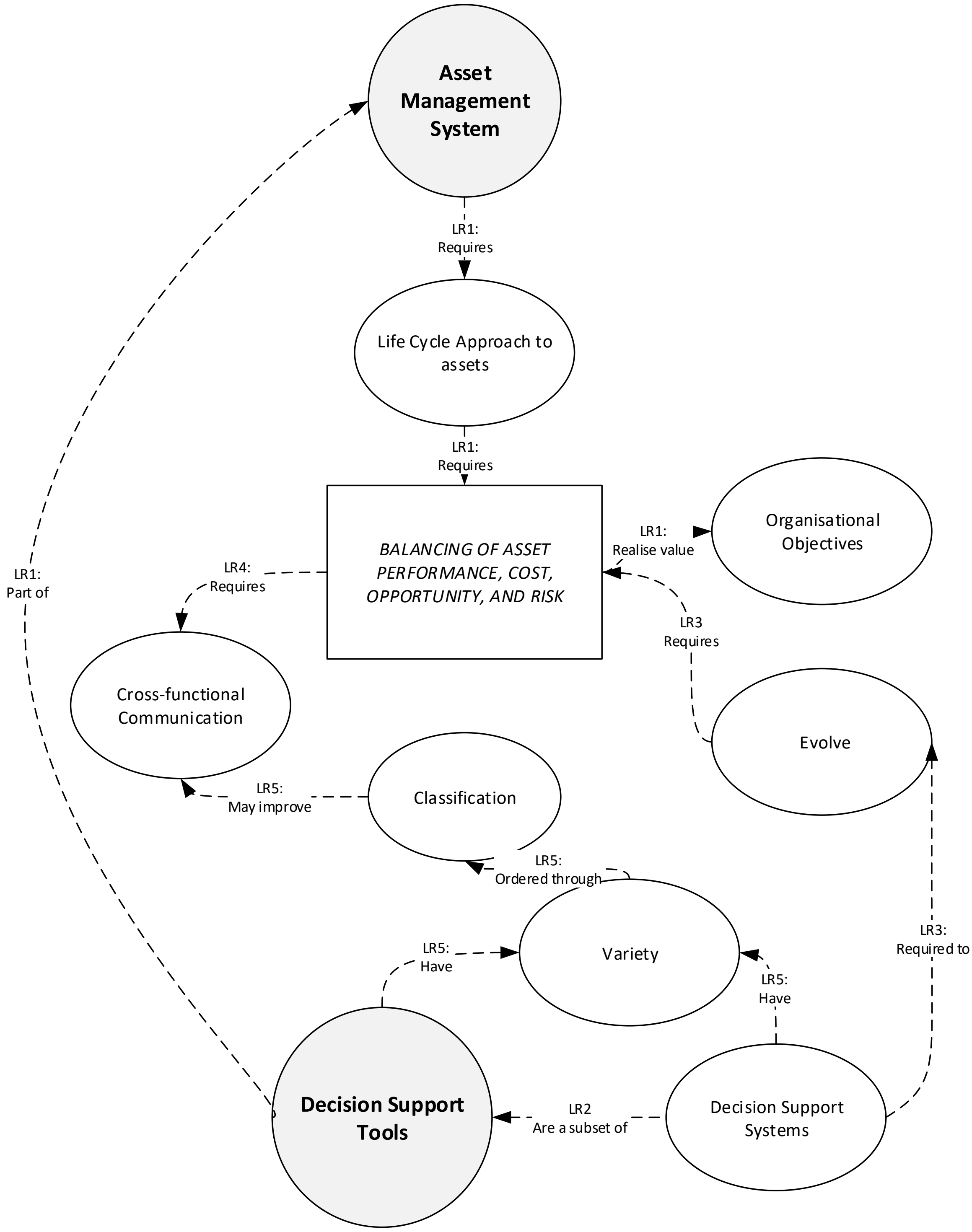


Figure 11. Literature review concept map

The concept map identifies five relationship pathways (LR1 – LR5):

LR1: The literature showed that within the UK energy sector aligning with the requirements of the ISO 5500x:2014 Asset Management Standard is critical (2.1.3). Therefore, within this sector, the Standard is central in shaping how AM is conducted in practice.

ISO 5500x:2014 aims to realise the value from assets and in doing so contribute towards achieving the organisational objectives. A holistic approach to assets is taken whereby asset performance, cost, opportunity and risk is managed across the lifecycle of the asset (2.1.3).

DSTs are used within the AM system to support making asset decisions: what assets to select and how to manage them (2.2.2 & 2.2.3). Within infrastructure organisations the performance of these tools has potential or actual value which can contribution towards achieving organisational objectives. Therefore, under the definition provided within the Standard, DSTs can be considered to be organisational assets (2.1.3).

LR2: Case studies of DST used within industry show them to use a range of approaches which encompass both manual and computer based tools (2.2.2). Within the academic literature DSS are defined as computer based systems which support making decisions (2.2.3). As such, DSS can be considered to be a subset of DSTs (2.3.1).

LR3: Central to decision system theory is that they should adapt and evolve (2.4.2). Therefore, performance would not be constant but can both increase and decrease. This being the case, as for physical assets, optimising the value of a DST would require the balancing of performance, cost, opportunity, and risk.

LR4: Balancing the performance, cost and risk of an asset requires cross functional communication (2.1.3). This is particularly pertinent for DSTs used in AM where the decisions they make can have implications across the organisation, and where their adaption and evolution will generally require the involvement of a range of areas and skills (2.4.2).

LR5: For decision systems, classification systems have been used as a means through which to assist effective cross-functional communication (2.4.1).

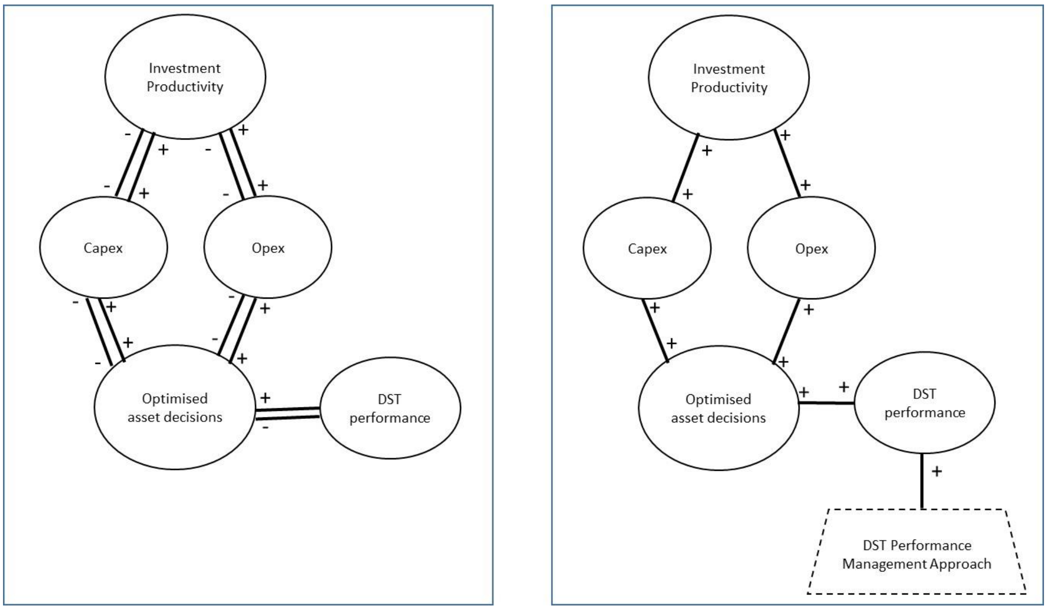
2.6 Research Challenge

The literature showed that within the infrastructure sector DSTs are being created as means through which to improve the efficiency and effectiveness of asset decisions.

However, the challenge of sustaining performance is well recognised. Often the challenge is not with developing an approach, but with sustaining the approach over time (Hicks and Matthews, 2010; Streit and Pizka, 2011; Studer, 2014; Van Dyk and Pretorius, 2014). Despite this challenge the on-going performance of business initiatives attracts only limited research attention. Reasons proposed include the lack of prestige attached to sustaining compared to creating and implementing new initiatives, and the increased difficulty of conducting longitudinal studies. There is also an element that in a changing business environment non-evolving initiatives are seen as targets for change and replacing one approach with another is not a failure, but a legitimate evolution of practice (Bourne and Neely, 2003; Buchanan *et al.*, 2003).

The review identified that when presenting new AM DST approaches limited considered has been given to managing their on-going performance. The lack of a systematic approach through which to manage DST performance represents a gap in knowledge. Potentially, if DSTs are not managed this may influence the efficiency and effectiveness of asset decisions, which in turn may impact investment productivity.

As a means of illustrating the envisaged causal relationships visual representations of the current (a) and desired (b) situations were created (Figure 12). The approach used in creating these representations was based on a method proposed by Blessing and Chakrabarti (2009). Factors are linked by means of a '+' or '-', indicating whether they have a positive or negative effect.



(a) Current situation *(b) Desired situation*

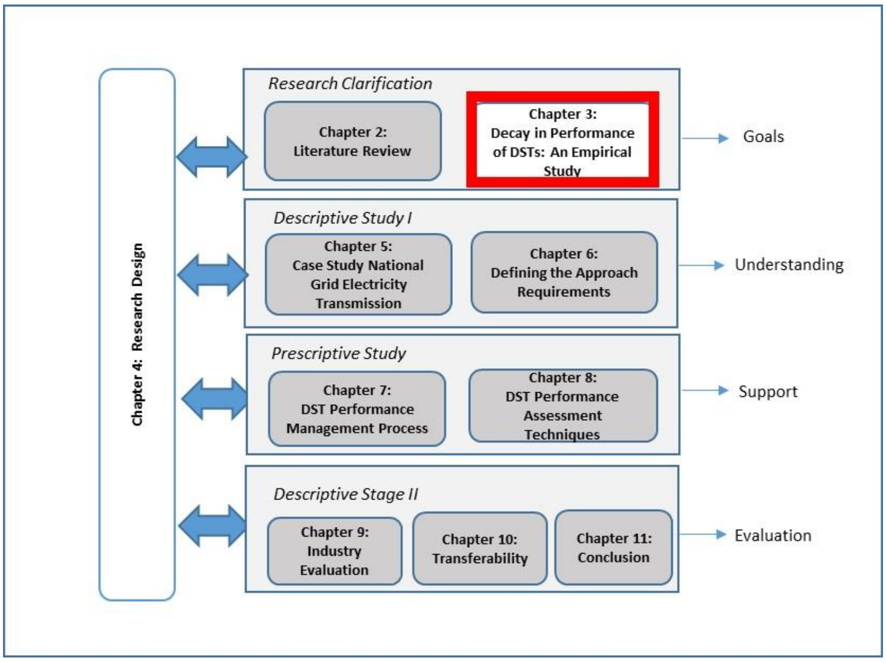
Figure 12. Visual representations of the (a) current and (b) desired (b) situations

The current situation (a) depicts that the performance of a DST can have either a positive or negative effect on optimised asset decisions. In turn, this can have either an positive or negative effect on Capex (capital expenditure) and/or Opex (operational expenditure) which can affect investment productivity either positively or negatively.   The desired situation (b) is that the creation and utilisation of a DST performance management approach will result in a positive outcome for DST performance, and ultimately result in increased investment productivity.

The research challenge was therefore to create an approach for managing the performance of AM DSTs which aligns to the International Standard for AM ISO 5500x:2014.

However, when defining the research challenge an assumption was made that DST performance can change. Although the literature supported that this was a reasonable assumption, there was no empirical evidence that this was happening in practice. If DST performance does not change (or if the change is always in a positive direction), there may be no requirement for approaches through which to manage DST performance. Chapter 3 details an empirical study undertaken with AM practitioners to test whether DSTs do experience a decay in performance.

Chapter 3: Decay in Performance of DSTs: An Empirical Study



This Chapter presents an empirical study that tests whether amongst expert AM practitioners there is a perception that DST performance decays. First, the three-stage approach used to conduct this study is detailed (3.1). The results are presented and discussed (3.2). Conclusions are formulated (3.4). Finally, summary points highlighting the key findings are provided (3.5).

3.1 Empirical Study Approach

In ascertaining whether DSTs experience performance change a qualitative approach, based on the experiences of practitioner subject matter experts, was used. There were two main reasons for this approach. First, the lack of available DST performance data, and the wide variation in the scope and attributes of DSTs, meant there would be difficulty in both accessing and drawing generalisable conclusions from quantitative data. Second, this research constitutes applied research. In applied research the value is to an extent dependent on whether the solutions it creates are successfully implemented (Hedrick *et al.*, 1993). In reality, whether an approach for managing DST performance management is adopted within industry will depend greatly on whether the AM community consider there to be a challenge that needs to be addressed.

Figure 13 visualises the three-stage approach used within this study. First, input was obtained from a NGET subject matter expert (Stage 1). The purpose of this stage was to define the term ‘performance’ within the context of this research. Next (Stage 2) the research was presented at the Institute of Asset Management Conference (June 2016). This provided a means of recruiting practitioners to the study. Third, the hypothesis was formally tested by way of an on-line questionnaire conducted amongst expert practitioners working in the field (Stage 3).

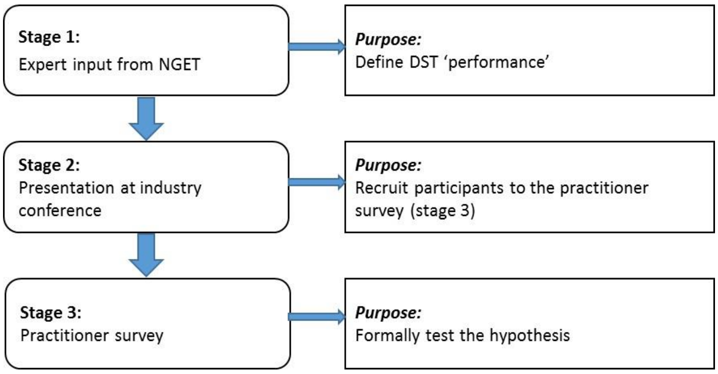


Figure 13. Empirical study approach

3.1.1 Stage 1: Expert Input from NGET

The literature shows that when measuring *performance* an extensive range of criteria might be used (DeLone and McLean, 1992). During Stage 1, a NGET subject matter expert provided input in order to define ‘performance’ in the context of this research.

The collaborative nature of this award facilitated access to subject matter experts within National Grid Electricity Transmission (NGET). The expert who participated in this study was chosen based on their extensive breadth of knowledge and experience both within asset management, and in the creation and operation of DSTs. In detail:

(1) In excess of 20 years’ experience within the energy sector, and 15 years’ within asset management at NGET.

(2) Technical Secretary for the Institute of Asset Management (IAM) Patrons Group. The IAM Patrons are an exclusive group of corporate members committed to a high level of activity and engagement with the Institute. In exchange for significant support to the Institute, Patrons have great influence on the direction of the Institute and the development of the asset management discipline (IAM, 2017b).

(3) Historic responsibility for the creation and implementation of the Whole Life Value Framework (WLVF). The WLVF is an enterprise wide, manual DST, which is

currently used with NGET to support asset acquisition and operational management decisions (see Chapter 5, 5.4.1)

(4) Current line-management responsibility for subject matter experts who operate the NGET Network Output Measures (NOMs) DST. The NOMs DST is a computer-based tool used in regulatory reporting to the UK energy regulator, Ofgem (see Chapter 5, 5.4.2).

Within its common terms and core definitions The International Organization for Standardization define ‘performance’ as a ‘measurable results’. In the context of the ISO AM Standard, this ‘measurable result’ is in relation to the value it contributes towards achieving organisational objectives (BS ISO 55000 Series: 2014). Input from the NGET subject matter expert identified DST *performance* to be a product of *value*, and *use*. The inclusion of *value* as a criterion for performance provided alignment with the ISO AM Standard. The incorporation of *use* as the second criterion reflected empirical evidence that *use* has a causal effect on the overall net benefits of a decision system (DeLone and McLean, 1992; DeLone and McLean, 2003). In this regard, a DST can offer potential value but unless it is used, that value will not be realised.

3.1.2 Stage 2: Presentation at Industry Conference

To recruit participants for the study the research was presented at the Institute of Asset Management Conference, Edinburgh, June 2016. The IAM Conference is an annual, industry focussed, international conference. It was attended by over 350 AM practitioners with delegates representing all of the key UK infrastructure organisations across the energy, water and transport sectors including: National Grid, Scottish Power, Network Rail Infrastructure Ltd, Highways England, Anglian Water Services, and Scottish Water (IAM, 2016a).

The research was presented during a parallel session and was attended by ~20 delegates. Feedback received through emails following the presentation supported DST performance decay and the need for the creation of approaches through which DST performance could be consistently managed (Vignette 1 & 2).

Vignette 1. Asset Owner: “decision support tools have been quickly discarded and/sometimes viewed as no benefit”

Vignette 2. Asset Owner: “[DST performance management] is an area that we don’t really consider and if we do it is very informally and inconsistent”

3.1.3 Stage 3: Practitioner Survey

Stage 3 involved an on-line questionnaire of practitioners working in AM. The use of industry experts was considered important as the literature had identified that AM is led by practitioners and governments, rather than from within the academic community (Too, 2010). Additionally, the aim of the research was to create a conceptual approach to manage the performance of decision support tools used within an Asset Management context. For there to be uptake, industry needed to recognise there to be a challenge.

The study was conducted over a four-week period (July/August 2016). The sixteen participants were recruited through five methods: volunteers recruited as a direct result of the poster presentation at the IAM Conference (stage 2 of the study), contacts made during the IAM Conference who were not exposed to the poster presentation, personal contacts made through previous research collaborations, via the Institute of Asset Management LinkedIn group, and through a call posted on a personal LinkedIn account. The reason for this recruitment mix was to mitigate the bias that may have been introduced by exposure to the conference presentation. The survey participants represented key UK and international asset owners and international consultancies working across the water, energy, and transport sectors. This included three UK water companies, one UK and two non-UK electricity transmission businesses, and a non-UK municipality. A breakdown of the participants is provided in Table 7.

Table 7. Survey participant composition

Recruitment Method	Number of participants	Sector Involvement*			
		Water	Energy	Transport	Other
IAM Conference – Following Poster Presentation	6	5	4	3	1
IAM Conference – Not Exposed To Poster Presentation	3	2	3	2	1
Personal Contacts	4	1	3		
IAM LinkedIn Group	1				1
Author's LinkedIn Post	2		1		1

* *Some organisations reported being involved in more than one sector*

The questionnaire (Appendix A) was conducted through an on-line survey platform and was structured to obtain: Participant and organisational information (questions 1 – 12); a closed question to elicit whether the respondents thought performance decay was occurring (question 13); an open question to provide support for the response made to question 14.

Participant information was used to validate expertise and focussed on length of service and responsibilities held. Of the 16 participants 15 confirmed that they had been employed in AM for more than 5 years, with the other having between 1-2 years' experience. All but one of the participants were involved with the development (11), implementation (10), or operation (11) of DSTs. The other, although not declaring a direct involvement with DSTs, held a senior (Vice President) role within an electricity transmission company and as such although not a direct user, was a decision maker who used the outputs of DSTs in decision making.

The organisational information was captured for use in analysis. It allowed the comparison of results across business types i.e. asset owners versus consultancies and ensured that in reaching conclusions the three sectors (water, energy, and transport) had each been considered.

Question 13 posed the question of whether DST performance decay occurs. To mitigate against acquiescence bias - the tendency of people to agree rather than disagree with a statement (Nunnally, 1978) - two versions of the question were created either supporting or opposing performance decay.

Supporting: ***After implementation the performance of tools used to support physical asset selection decays: they stop being used or the value they offer reduces.***

Opposing: ***After implementation the performance of tools used to support physical asset selection does not decay: they continue to be used and the value they offer remains the same or increases.***

The software randomly selected which of the two version was presented to the participant with responses made against a Likert scale: completely agree, agree, disagree, and completely disagree. The use of a scale, rather than a dichotomous response was intended to increase the granularity of the data, which if required, would facilitate more in-depth analysis.

Finally, participants were asked to provide comment to support their choice (question 14). The aim of this question was to provide a second dataset against which to triangulate the results, and to provide an insight into the factors considered to affect performance. In creating an approach through which to manage DST performance, understanding the factors that can affect DST performance would be vital.

3.2 Empirical Study Results & Discussion

To determine whether performance decay was occurring the analysis first considered the closed question response (question 13). These results demonstrated that opinion was split: ~56% supported that performance decay was occurring, versus ~44% who did not.

It also showed no correlation existed between the response made and organisation type. That is, whether the participant was an asset owner or consultancy (Table 8).

Table 8. Survey analysis. Support and opposition for performance decay by organisation type

Organisation Type	Supporting Performance Decay	Opposing Performance Decay
Asset Owner	5	4
Consultancy	3	2
Both	1	1

With the preliminary analysis providing little by way of insight, the analysis progressed to consider the qualitative comments (questions 14).

The data shows that although the survey defined performance using the criteria of *use*, and *value*, participants were still able to apply differing interpretations to the question. An example of this is seen by comparison of response 3 and 5 (Table 9). In response 3, the participant supports the occurrence of performance decay stating "*Loss of momentum or ongoing support due to staff movement/departure, re-organisations or restrictions on implementing improvements".* In this example DST performance decay is said to occur and this is due to a change in the environment in which the DST operates. There is however, no indication that the tool is not meeting the design specification against which it was created.

On the other hand, the participant in response 5 does not support the occurrence of performance decay. Justification for this response was "*The tools are still valid - it is the data that decays".* In this example, the participant's response to whether performance decay was occurring (question 14) was based on an assessment of the functioning of the tool, rather than the net benefit using the DST delivers.

The purpose of DSTs used in an AM context is to improve the efficiency and effectiveness of decision-making and in doing so contribute towards the organisation achieving its objectives. Consequently, assessments of DST performance should not be based simply on whether tools are performing to specification, but the contribution they make towards realising organisational goals. Applying this perspective to analysis of the comments ~81% of responses were interpreted as supporting the occurrence of DST performance decay (Table 9).

Table 9. Analysis of qualitative comments applying a system perspective to performance decay

RESPONSE NO.	QUANTITATIVE RESPONSE SUPPORTING OR OPPOSING DECAY	QUALITATIVE COMMENT	QUALITATIVE RESPONSE SUPPORTING OR OPPOSING DECAY
1	Support	Organisations changes as well as their environment. Tools therefore should also change to accommodate such changes. Unfortunately decision support tools typically remain fixed and in some cases obsolete. As a consultant, my opinion is that asset owners should hire (at least 1) technical specialist that is able to understand and modify/adjust decision support tools. From my experience, a well-rounded data scientist is the best role for such task.	Support
2	Support	Support tools are vital to the maintenance of an asset/assets.	Inconclusive
3	Support	Loss of momentum or ongoing support due to staff movement/departure, re-organisations or restrictions on implementing improvements.	Support
4	Oppose	If the support tools are no longer used, it's usually caused by several factors not related to the value or effectiveness of the tool	Support
5	Oppose	The tools are still valid - it is the data that decays	Support
6	Oppose	In theory value of AM tool application in AM lifecycle increases. However my experience as a consultant is that theory and reality is often different. Use of AM tools is often used to justify operational decisions rather than strategic ones. The link and value is not evident in many situations	Support
7	Oppose	Our tools are not dynamic, while the external environment is. Strategy, objectives, legislation, operating regimes, are changing at an accelerating rate, I feel out tools are too static and are not dynamic enough to deal with such rate of change.	Support
8	Oppose	Agreed in principle - performance of tools do not degrade, however, value steadily decrease as the level of analysis improves/ better information becomes available.	Support
9	Oppose	Based on experiance. Users get more confident to use them and explore new opportunities.	Oppose
10	Support	I believe that decision support tools require constant energy to remain current. There are a number of factors that will affect their effectiveness including: - changing organisational objectives / priorities - changing regulatory environment - remaining current amongst other initiatives - training and competence of resources using the tools may degrade - a complacency that we 'know the answer' may creep in	Support
11	Support	The question is phrased in a way that it does not determine the difference between the Product, Process or People. The performance of a tool is fully dependant on the process and people employed to use it and either of those attributes changing can result in performance decay. The statement made post comma is really a separate question. FYI tools may be continued to be used but their value may also decrease if the information is not pertinent to the needs of the respective company.	Support
12	Support	Tools which assess response actions (eg: fix or replace) must evolve to match the complexity of the decision inputs which almost always attempt to balance the two core decision drivers, commercial asset optimisation and risk mitigation. Tools must assess both current and future scenarios as specific assets acting as single components within dynamic systems. Notwithstanding, this multifaceted and dynamic assessment capability must be weighed against the value of stable history collected by the tools to ensure future data links properly when scoping any required functional tools changes.	Support
13	Support	Predominant value is taken from the 'low hanging fruit', once the initial efficiencies have been taken then the tool will usually support the running of business as usual, but new approaches are normally required to deliver additional value.	Support
14	Support	Because people consider it like a moda	Support
15	Support	Experience of implementation of Decision Support Tools	Support
16	Opposed	Some of these tools are used on a continuous basis to support our assets.	Inconclusive

In undertaking the analysis, two responses were considered to be inconclusive (2 & 16). In response 2 the participant indicated that they support the occurrence of performance decay their comment "Support tools are vital to the maintenance of an asset/assets" did not provide justification for their support. In response 16 the participant did not support the occurrence of DST performance decay but again their comment "Some of these tools are used on a continuous basis to support our assets" was not considered to be justification as highlighted by response 11, DSTs may continue to be used even if their value decreases.

Amongst the remaining 14 responses, 13 were considered to support the occurrence of performance decay. Whereas, some responses suggested this was happening (e.g. response 3 and 7), others were less definitive and required researcher interpretation. For example, response 4 states, "**If** the support tools are no longer used, it's **usually** caused by several factors not related to the value or effectiveness of the tool". By using the word "if" the participate does not explicitly state that decay is occurring. However, the use of "usually" supported that it did.

Although the results of the analysis demonstrate general agreement of the occurrence of performance decay, one participant did not agree. Response 9 indicated that rather than performance decay, DST *use* can bring about increases in its performance. Cognitive evolution, whereby users identify new requirements through experiencing the system (Arnott, 2004), suggests that DST performance management might not only be viewed as an activity to reduce risk, but as a way to identify opportunities to realise additional value.

Amongst the comments there is strong support for environmental change as a factor in DST performance decay. Analysis presented within Table 10 shows the comments mapped to evolutionary environmental causal factors (Arnott, 2004).

Mappings are demonstrated for three of the factors: personnel change (response 3, 10, 11 & 4), internal organisational change (response 1, 3, 7 & 10), and industry change (response 7 & 10). This infers that if DST are not identifying and adapting to changes in these environment there is a risk to their performance. Whilst three factors are not considered to affect DST performance: technology change, co-evolution, and merger and acquisition, this does not necessarily mean that they do not create DST performance change.

Technology change (the availability of new technology on which DST approaches can be based) and coevolution (the risk introduced by a change in an interlinked system) were not identified as factors that affect performance. This may reflect the skills focus of the respondents (not employed within an IS environment), or in the case of technology change not adopting new technology can be considered to be a missed opportunity, rather than a reason for performance to decline.

Merger and acquisition was also not highlighted as a reason for DST performance change. This is perhaps explained by the nature of the businesses surveyed that comprised of utility businesses and large consultancies. Within these businesses merger and acquisition would be expected to be an uncommon event.

Table 10. Mapping of evolutionary environmental causal factors to DST performance risk

Environmental Causal Factors	**Survey Qualitative Response**
Technology Change	No support
Personnel Change	Loss of momentum or ongoing support due to staff movement / departure (response 3) Training and competence of resources using the tools may degrade (response 10) The performance of a tool is fully dependent on the process and people employed to use it (response 11) Because people consider it like a moda (response 14)
Internal Organisational Change	Organisations change (response 1) Loss of momentum or ongoing support due …reorganisations or restrictions on implementing improvements (response 3) Strategy, objectives….are changing at an accelerated rate (response 7) Changing organisational objectives / priorities (response 10)
Merger and acquisition	No support
Industry changes	Legislation, operating regimes…are changing at an accelerated rate (response 7) Changing regulatory environment (response 10)
Coevolution	No support

3.3 Empirical Study Conclusions

Analysis of the qualitative inputs of subject matter experts, working in sixteen key UK and international infrastructure organisations and asset consultancies, found support for the occurrence of performance decay (~81%).

However, the results highlighted that when asked to assess DST performance, practitioners can apply differing interpretations. These include performance as a measure of whether the tool is performing to specification; the satisfaction of the users; or the overall benefits to the organisation. To increase rigour, robust methods through which to consistently assess DST performance are required.

Environmental change was identified as a factor for performance change in six of the sixteen responses. This supports the view expressed in the literature of the importance of environmental causal factors in instigating performance change (Arnott, 2004). This would imply that to mitigate the risk of change, DST performance management cannot consist of a one off measure, but should involve continual monitoring throughout the operational life of the tool.

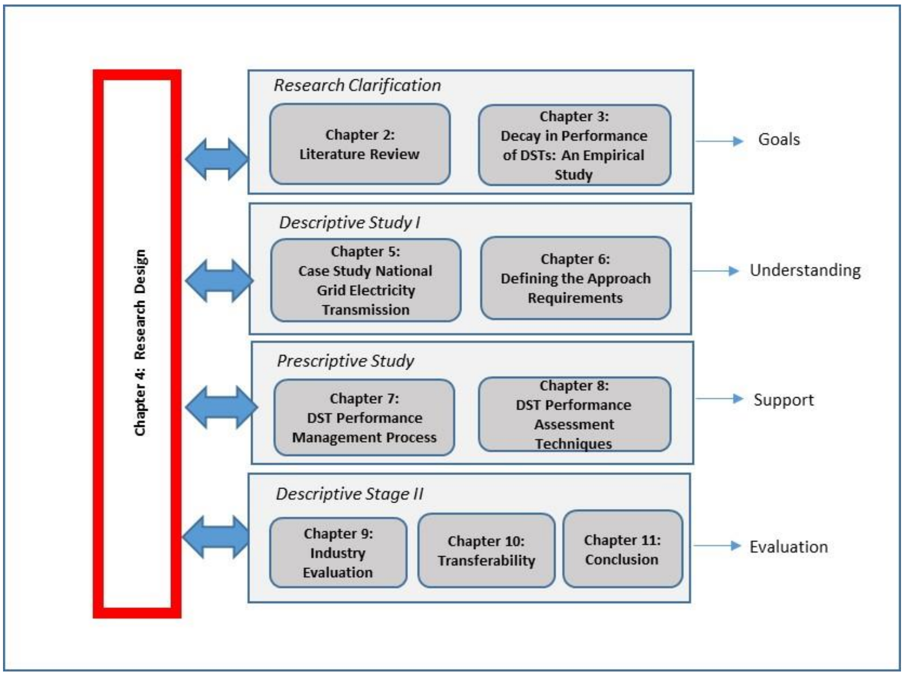
Although the majority of respondent supported the occurrence of DST performance decay, one respondent did not agree. Rather, they indicate that performance is enhanced through use. Although this view was not generally expressed, it does not mean that enhanced DST performance was not possible. If it were accepted that cognitive evolution of DSTs was possible, this would suggest that managing performance should not only look to mitigate risk, but also to identify opportunities to increase performance above that seen at first introduction.

3.4 Chapter 3 – Summary Points

- Methods are required to ensure consistency in measuring and reporting DST performance.
- Environmental change introduces a risk to DST performance throughout the operational life of the tool.
- If cognitive evolution does occur, it would offer the opportunity to enhance DST performance over and above levels seen at first implementation.

In combination, the literature review and the empirical study supported the need for the creation of an approach through which to manage DST performance. The design for the research to realise that output follows.

Chapter 4: Research Design



The research design details the approach taken in conducting the four stages of the research. Within this Chapter an introduction to the elements of a research design (4.1) and the *key components* are described (4.1.1). Next, the key components for this research project are define. Research constraints (4.2). Purpose (4.3). Methodology (4.4): philosophy (4.4.1), strategy (4.4.2), methods (4.4.3), analysis (4.4.4), evaluation (4.4.5) and ethics (4.4.6). Finally, summary points highlighting the key findings are provided (4.5).

4.1 Research Design

Having a coherent research design is important as it has a bearing on the way in which research is conducted, and frames the understanding to be taken from the conclusions presented (Bell, 2010; Denscombe, 2010b; Hedrick *et al.*, 1993). A 'good' research design should do three things: explain how the key components of the research project link together; provide the general approach the research will be taking and the rationale for the choices that have been made (Figure 14).

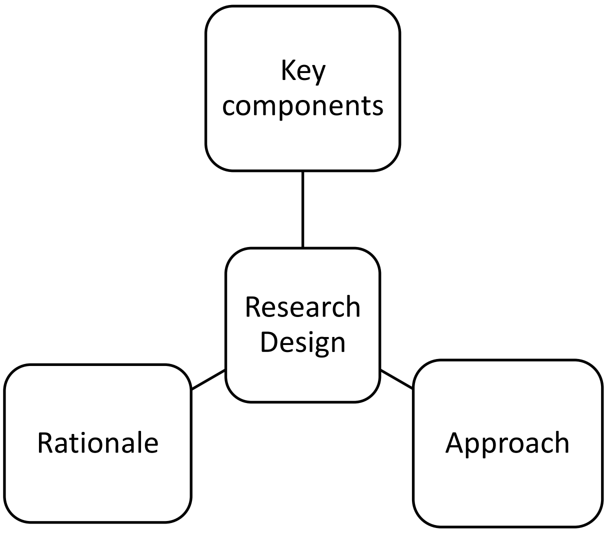


Figure 14. Elements of good research design (Denscombe, 2010b)

4.1.1 Key Components

The key components are the building blocks of the research design. The literature shows there to be an array of categories used when defining these building blocks. Crotty (1998) defines four categories: epistemology, theoretical perspective, methodology, and methods. This proposed that the choices of epistemological perspective, will influence choices made later in the design for example, the methods which are used.

Similarly, Saunders *et al.* (2009) acknowledge the interconnected nature of the design presenting the construction of a research design as a Research Onion©. As the name implies the categories are arranged in layers moving from philosophies, through approaches, strategies, choices, time horizons, and finally ending with techniques and procedures. Thus, six, rather than the four categories offered by Crotty (1998).

Comparing the two, it is not purely a case that the Research Onion© has added more granularity across the design. Although there is more detail in some areas (i.e. a specific category which considers time horizons), there is less detail at the philosophical level. That is, whereas Saunders *et al.* (2009) offer a single category of 'philosophies', Crotty (1998) offer two categories of epistemology and theoretical perspectives.

The key components of this research project were identified based on the Denscombe (2010a) model (Figure 15). This model was considered advantageous as it highlighted that not only were there connections between components within the methodology, but between the methodology, and the research constraints and purpose (aim, research questions/objectives, and outputs). Furthermore, the categories considered under methodology extend past defining the methods to include the additional categories of evaluation and ethics. Although, this complicates the ‘onion’ thinking, the inclusion of these additional categories was considered necessary when communicating the complete research design.

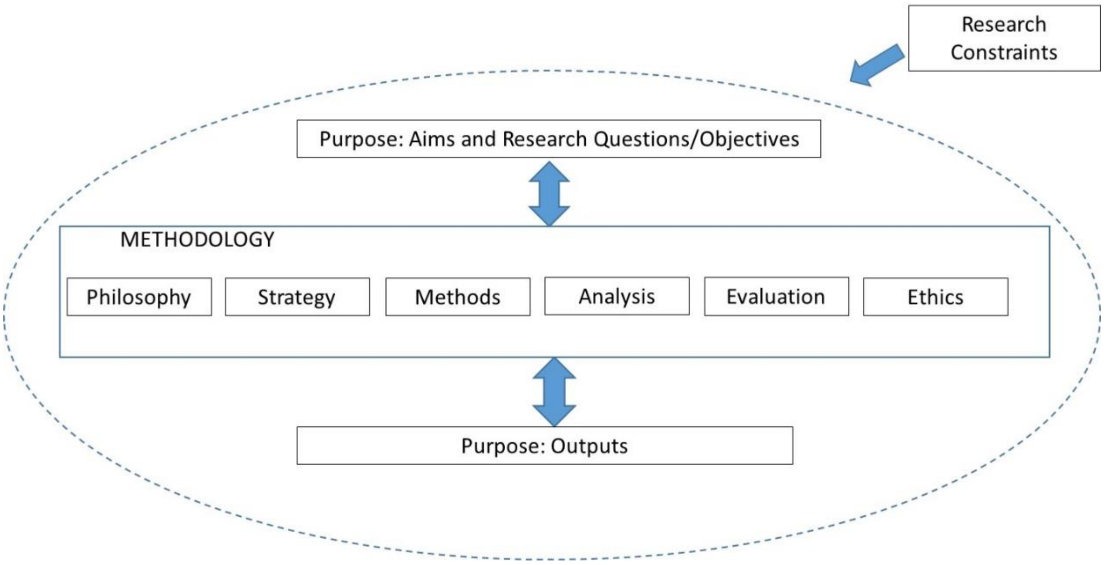


Figure 15. Key components of the research design. Adapted from Denscombe (2010a).

4.2 Research Constraints

The iCASE funding award under which this was research was conducted supports **applied research** whereby the researcher works with an industrial partner to address a ‘real-world’ industrial need. The industrial partner for this research was National Grid (NG).

The major difference between basic and applied research can be seen in their purpose. The primary focus of basic research is to expand knowledge. Although it is hoped that the new knowledge will eventually help in solving particular problems, it is not its specific intent. Applied research on the other hand uses scientific methods to seek understanding, with a specific aim of addressing a societal challenge. As such, applied research is often conducted in a complex, chaotic, and highly political environment (Bickman and Rog, 2009).

Although having many similarities, there are differences to be seen in the purpose, context and methods used. A summary of these differences is presented within Table 11.

Table 11. Comparing basic and applied research (Hedrick et al., 1993)

BASIC	APPLIED
Purpose	
Develop universal knowledge Answer single questions Discover statistically significant relationships or effects	Understand/address problems Answer multiple questions Discover practically significant relationships or effect
Contexts	
Academic settings Self-initiated Funded by grants Solo researcher Single discipline Lab or class Flexible Lower cost sensitivity Less time pressure	Government, foundation, business/industrial setting Client initiated Funded by contracts Research team Multidisciplinary Field Inflexible Higher cost sensitivity More time pressure
Methods	
Internal validity Construct of cause Single level of analysis Single method Experimental designs Direct observations	External validity Construct of event Multiple levels of analysis Multiple methods Quasi-experimental designs Indirect observations

Although recognised as a simplification, the table highlights how undertaking an applied research project can put constraints around the way it is conducted.

Within this research, five primary constraints were identified:

1. **Research Focus:** An overarching research focus of DSTs used within an AM context was outlined.

2. **Time:** The research was funded for a period of 42 months. The time constraints, and the governance which would be necessary ahead of industry implementation, dictated that the scope was restricted to defining a conceptual approach. The future research opportunities that look to take the approach forward from the conceptual state are provided as part of the Conclusion (Chapter 11, 11.4).

3. **Existing Knowledge Base:** The existing body of knowledge in this area was limited. AM is a new and emerging academic field. As such, there was limited available data and theory on which to build this research.

4. **Access to Participants:** Established links with industry AM communities were limited.

5. **Constraints on approach design:** The literature identified that although not a specific condition of their licence, certification under the ISO 55001:2014 AM standard is strongly encouraged by the UK energy regulator, Ofgem. Consequently, complying with the standard is a constraint on the approach design.

6. **Industry Drivers:** Within the community there has been a movement towards considering a broader range of non-engineered assets within AM. For example, a recent academic work championed the inclusion of natural assets when managing water (Papacharalampou *et al.*, 2017), and the recent Institute of Asset Management Conference (November, 2017) and a IAM publication (IAM, 2017a), identifies the importance of data and having a data management strategy, as part of AM system.

   Although there was a general widening of the scope of the assets considered, previous to these work there appears to be no acknowledgement of the importance of DST management. Importantly, there had been no call from within the AM community, or industry regulators for a DST performance management approach to be developed. This work leads the field in this area.

   This creates two issues. First, there was little existing buy-in, or external drivers to encourage industry to participate in the research. Second, the requirements for a DST performance management approach had not crystallised; they were vague and undefined.

The challenge was in planning the research scope and approach to overcome these identified research constraints.

The literature shows there to be a multitude of competing and complimentary theories and models for designing a 'support'. A review by Chakrabarti and Blessing (2015) provides a summary of more than 35 of what they consider to be the major works. Although there are numerous approaches, they can be broadly categorised as falling into two categories: sequential and iterative/incremental. Sequential models are generally referred (although as pointed out by both Boehm (1988) and Larman and Basili (2003) perhaps incorrectly), as waterfall models. The requirements are gathered and progressed through a number of sequential steps (Figure 16).

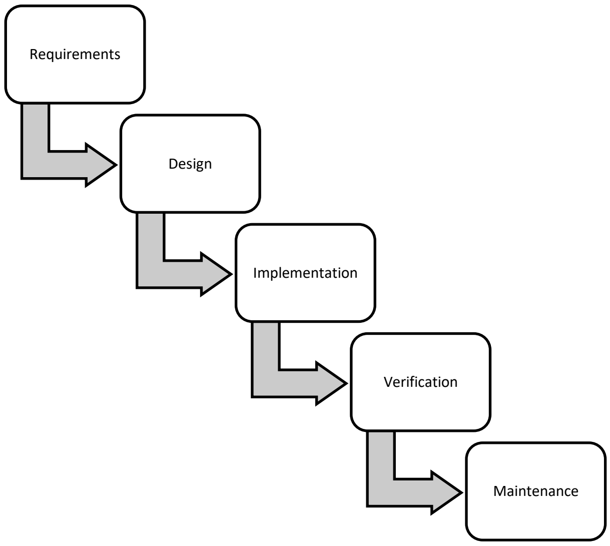


Figure 16. Example of waterfall approach

The limitations of the waterfall approach are well reported. Indeed, a widely cited 1998 report, which analysed 23,000 information technology projects, identified that the top reason for failure were problems associated with waterfall practices (Larman and Basili, 2003).

Iterative and incremental approaches do not follow a series of sequential steps but apply a cyclical or spiral of development, which delivers a product with an agreed level of functionality, or functionality which is bounded by time or risk (Boehm, 1988). Falling within these iterative / incremental approaches is evolutionary design. The premise of evolutionary design is that during the process of development the customer will have a changing perception of what is possible, wanted, and needed (Boehm, 1988; Larman and Basili, 2003). The developer works with the customer to capture these changing requirements as they arise which often involves the creation of an initial product. This 'prototype' provides a catalyst for the generation and convergence of requirements (Larman and Basili, 2003; McCracken and Jackson. M. A., 1982; Boehm, 1988). As such, it is particularly suited to the very early stage of design, or where the customer is unclear about what it is that they want.

Within this research, an evolutionary design approach is used (Figure 17). The reasoning was that there was no clear direction from either industry, regulations or regulators, or International Standards on what a DST performance management approach should look like. By adopting an evolutionary approach, an initial 'prototype' was created which was expected to evolve as during the process, or as a consequence of the process changing the environment, the requirements of the stakeholders emerge and crystallise.

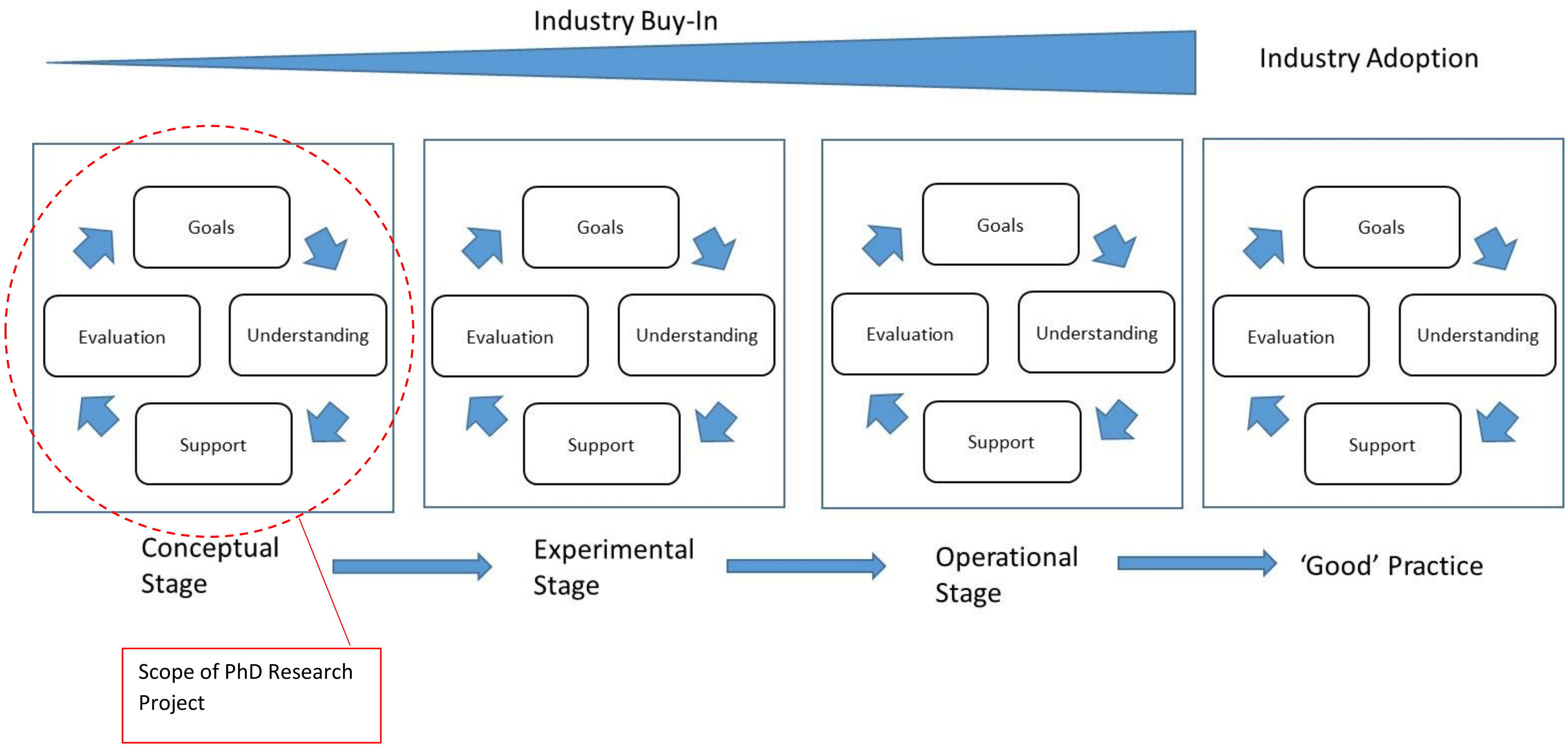


Figure 17. DST performance management approach evolutionary research pathway

Figure 17 shows the overarching research pathway. It shows a clear progression from conceptual stage through to adoption as industry ‘good’ practice. Within each stage there is a cyclical process which mirrors the four stages seen within the Blessing and Chakrabarti (2009), DRM framework (Chapter 1, 1.1).

The scope of this PhD is restricted to the creation of a conceptual approach. The purpose of the research is now defined.

4.3 Purpose

The *purpose* outlines what the research is trying to achieve and comprises of *aim, research objectives,* and *output(s)*. Together they form a ‘top down’ network of elements. Figure 18 provides the research purpose elements within this research.

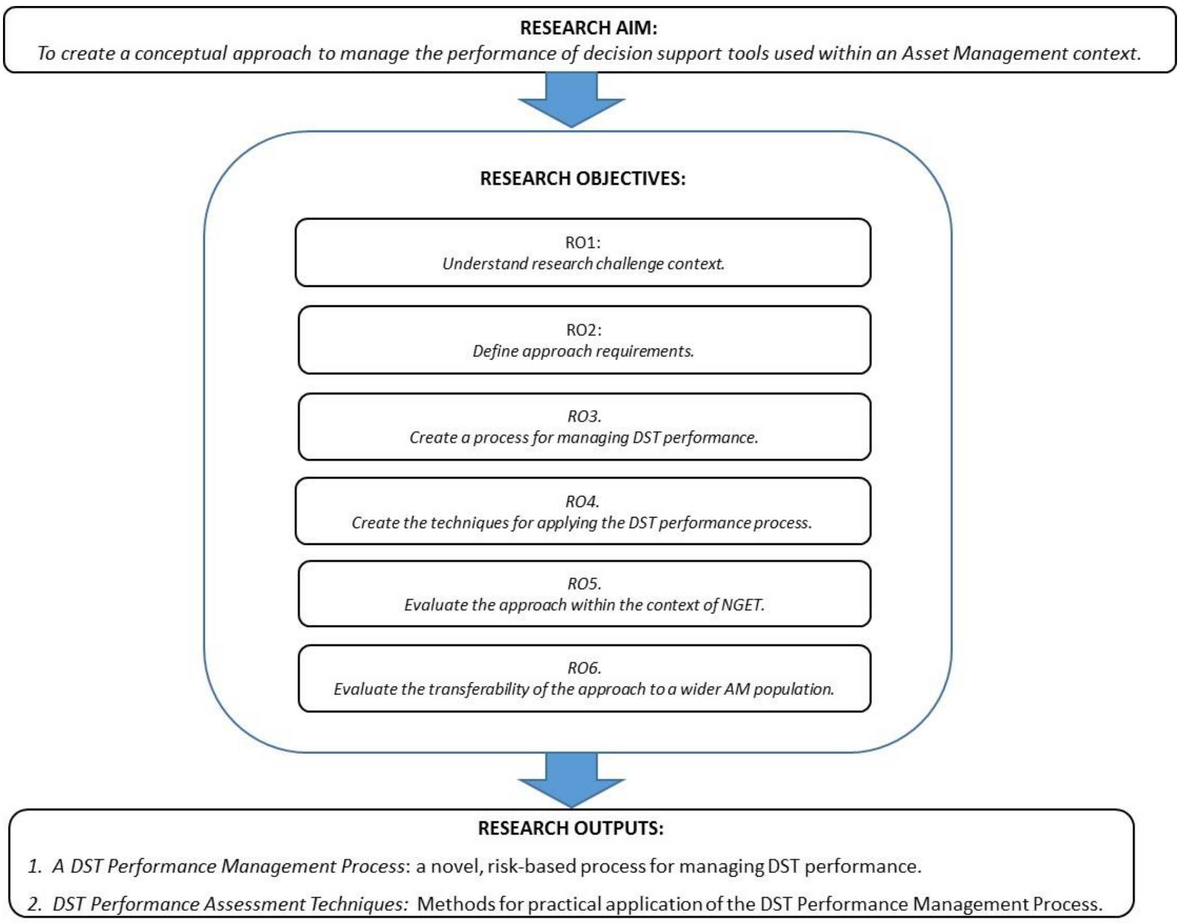


Figure 18. Research purpose

4.4 Methodology

The methodology comprises the philosophy, strategy, methods, analysis, evaluation, and ethics. Combined, they detail the scientific approach used in delivering the output.

4.4.1 Philosophy

It is acknowledged that people may hold different perspectives through which they might view the world. By defining the philosophical position taken during a study it provides the audience with the logic for why a certain approach may have been adopted, and identifies the position of standing in which any conclusions have been reached. Although this research acknowledges that defining the research philosophy is important, it also acknowledges that it is an extremely complex subject, with a bewildering array of theoretical perspectives possible (Crotty, 1998). Consequently, it defined a basic position and did not attempt to delve too deeply into the minutiae.

In adopting a philosophy stance there are two underpinning questions to be considered: what is the researcher's underpinning belief of 'reality', and given that belief how would they go about gathering knowledge? These are known as ontology and epistemology.

Ontology, refers to the researcher's belief about social reality. The two basic positions are 'realists' and 'constructionists' (Denscombe, 2010a). Realists have a belief that the social world exists irrespective and independently from any individual: that there is one reality. On the other hand constructionists believe that the social world is a creation of the human mind which is constructed and then reinforced by social interactions: there are multiple social realities (Denscombe, 2010b).

Unlike ontology, epistemology is not concerned with what reality 'is' but rather the underpinning logic as to how to acquire knowledge about it. Like ontology, there are two basic positions with each linking closely to either the realist or the constructionist viewpoint. The first 'positivism' is based on knowledge being gained through objective methods such as statistical measurement. Positivism links closely with the realist perspective. The alternative 'interpretivism', is not based on objective measurements but a standing that knowledge is gained by way of human interpretation. Interpretivism aligns with the 'constructionist' viewpoint (Denscombe, 2010b).

The basic stance taken within this research was constructionist, and interpretivism. That is, the approach requirements, the approach which is created, and the evaluation of the approach reflect the reality of those involved, at a certain point in time. The process of progressing the approach from conceptual design through to industry adoption will change perceptions of what is possible, wanted, and needed. This stance is supported by the use of an evolutionary research approach in which it is accepted that the approach will develop over time (4.2).

4.4.2 Strategy

A *research strategy* is the action taken to achieve the aims of the project (Denscombe, 2010a). This research used a case study of National Grid Electricity Transmission (Chapter 5) as the mechanism for generating understanding which was used to inform the creation of the approach (Chapters 7 & 8), and to evaluate its 'success' (Chapter 9 & 10).

When choosing which research strategy to adopt the literature showed there to be a number of options. Of these, none was considered 'best', but instead they offered a range that would will be more or less appropriate depending on the research project (Table 12).

Table 12. Research strategies and research purpose (Denscombe, 2010a)

STRATEGY	PURPOSE OF RESEARCH
Surveys	Measure some aspect of the a social phenomenon or trend Gather facts in order to test a theory
Case Studies	Understand the complex relationship between factors as they operate within a particular social setting
Experiments	Identify the cause of something Observe the influence of a specific factor
Ethnography	Describe cultural practices and traditions Interpret social interactions with culture
Phenomenology	Describe the essence of specific types of personal experience Understand things through the eyes of someone else
Grounded Theory	Clarify concepts or produce new theories Explore a new topic and provide new insights
Action Research	Solve a practical problem Produce guideline for best practice
Mixed Methods	Evaluate a new policy and gauge its impact Compare alternative perspectives on a phenomena Combine aspects of other strategies

Yin (1994), proposes that the suitability of a strategy can be gauged depending on three factors: the research question(s), whether it requires control over behavioural events, and whether the research is focussed on contemporary events. Denscombe (2010b) however suggests that the choice should not only consider suitability, but also feasibility of adopting a particular approach.

The overarching ambition of this research was that this approach would be used within industry and in doing so contribute towards improved asset investment productivity. For this to be realised there needed to be an understanding of how DSTs were being used and managed within industry, and what the stakeholder requirements for a DST performance management approach were. Case studies are considered to be particularly suited to understanding contemporary, complex relationships in social settings (Denscombe, 2010a; Yin, 1994). As such, it offered a suitable strategy. Although suitable, the question that remained was whether a case study strategy was feasible and furthermore, whether NGET were a suitable subject for a case study.

Under the terms of the award, it guaranteed the researcher access to the organisation for a minimum of three months, and stipulated that the project be co-supervised by an employee of the industrial partner. This industrial research partnership made conducting a case study of NGET feasible.

As well as offering a feasible strategy, other factors supported the suitability of NGET as the case study subject. First, being solely responsible for the transmission of high voltage electricity NGET play a major role within the UK electricity infrastructure. This necessitates the management of an extensive asset portfolio of £42.6 billion (National Grid, 2017b), with planned Totex investment of £16.4 billion over the period 2013 – 2021 (National Grid, 2012c). Second, they are active within the asset management community being patrons of the Institute of Asset Management. Through this role they are involved in cross-sector dialogue within regulators which is aimed at promoting good asset management practice (IAM, 2016b). Third, they currently operate in excess of 200 DSTs within their business, two of which are published as exemplars within an industry guidance document (IAM, 2015).

Whilst recognising the factors that support the choice of NGET, there are limitations to adopting a case study strategy. NGET represent a specific sub-set of the asset management community in terms of sector, size of organisation, regulation, and maturity of asset management practices. Furthermore, although case studies are widely used (Bell, 2010; Creswell, 2009; Denscombe, 2010a, b) critics question the value that can be associated with conducting a single study and whether this may introduce biased reporting (Bell, 2010; Denscombe, 2010a; Yin, 1994). Within this research, these limitations were addressed in two ways. First, although a single case study was used the approach was evaluated across three example DSTs used within NGET (Chapter 9). Second, the transferability of the approach to a difference infrastructure sector (water) was assessed (Chapter 10).

4.4.3 Methods

The *research methods* are the techniques used in gathering data (Denscombe, 2010b). Like research strategies there is no 'best' choice, each has advantages and disadvantages and the choice made is dependent on the purpose and constraints of the research project (Bell, 2010; Denscombe, 2010a, b; Gray, 2014). Although some methods are commonly linked with a particular strategy, if justified the researcher may choose a less usual method, combine a number of methods together, or triangulate to look at the topic from a variety of angles (Denscombe, 2010a).

This research adopts mixed, qualitative research methods including subject matter expert interviews, questionnaires, and focus groups. The use of qualitative research methods has sometimes received criticism for lacking scientific rigour. However, supporters argue that unlike quantitative research it is conducted in the social reality of the phenomena rather than based on the analysis of criteria selected by the researcher (Gray, 2014). Given the philosophical stance of this research, qualitative methods were considered best suited.

4.4.4 Analysis

Analysis is to gain understanding by describing, explaining, or interpreting data. The two basic positions of analysis are quantitative (numbers), and qualitative (words or visuals). The nature of analysis means that qualitative and quantitative methods are often linked to the research methods and the in-turn to the philosophical stance that has been taken. In comparing the two Denscombe (2010a) identified a number of elements where the two analysis approaches differ (Table 13).

Table 13. Distinction in the use of qualitative and quantitative analysis (Denscombe, 2010a)

Quantitative	Qualitative
Uses numbers as the units	Uses words or visuals as the units
Researcher attachment	Researcher involvement
Large scale studies	Small scale studies
Specific variables	Holistic perspective
Data analysis after data collection	Data analysis during data collection

Given the philosophical stance and qualitative methods used, qualitative analysis was considered the most appropriate approach. However, it is accepted that qualitative data can be open to multiple interpretation. The techniques used to provide assurance of the credibility of the research are detailed within the evaluation section (4.4.5).

4.4.5 Evaluation

An evaluation plan is a concept promoted by Blessing and Chakrabarti (2009). They advocate that although it is good practice to evaluate results throughout the process, it is essential to evaluate the end support that is created. The reason for this is that the effects can only be assumed during development because:

- the support is a creation based on assumptions that have been translated and extrapolated.
- the introduction of a support changes the environment.
- the context in which the support is created is dynamic.

It is suggested that valuation of the support (in this research the DST Performance Management Process and DST Performance Assessment Techniques) should occur at three levels: support, application, and success (Blessing and Chakrabarti, 2009). Support evaluation considers in-build functionality and consistency. Application evaluation considers whether the output can be used for the task for which it was intended and focusses on the usability. Success evaluation aims to identify whether the support has the intended impact.

In this regard support and application evaluation are akin to the terms verification and validation seen within the Institute of Electrical and Electronic Engineers (IEEE) Standard Glossary of Software Terminology (IEEE Std 6010.12 -1990 (R2002), 1990). Within this Standard verification is “the process of evaluating a system or component to determine whether the products of a given development phase satisfy the conditions imposed at the start of that phase”, validation is “the process of evaluating a system or component during or at the end of the development process to determine whether it satisfies specified requirements” (IEEE Std 6010.12 -1990 (R2002), 1990). Given these definitions, verification confirms that the product is built right – it conforms to specification - whereas validation confirms that the right product is being built – that it meets the customer’s needs.

Figure 19 presents the evaluation plan for this research. To aid communication and to align with commonly used industry Standards the terms *verification*, *validation* and *overall evaluation* have been used.

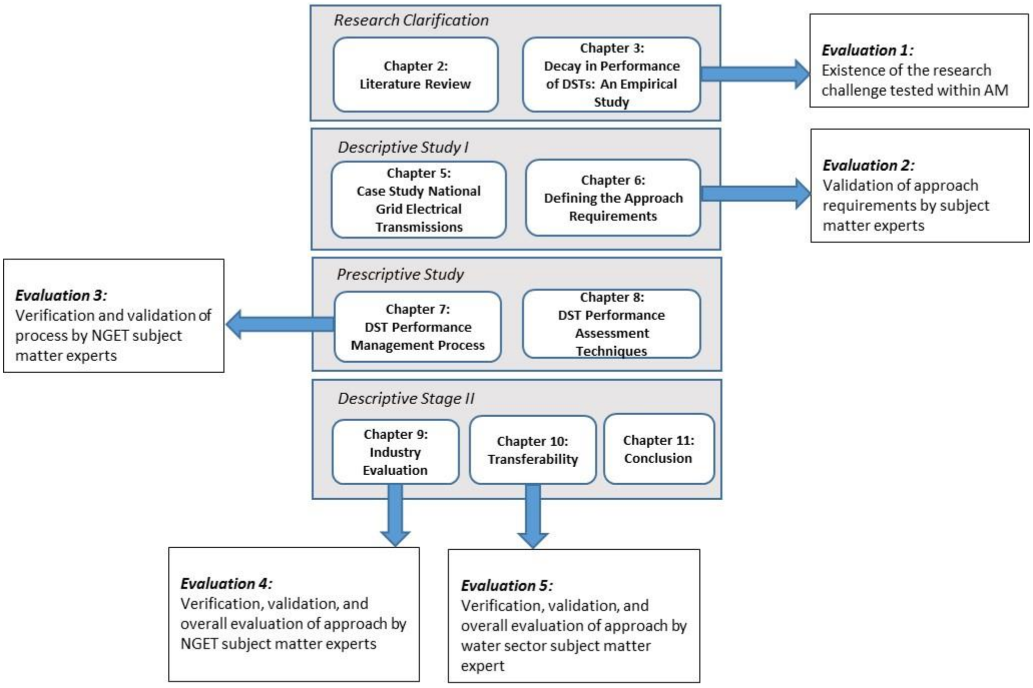


Figure 19. Research evaluation plan

Evaluation 1: The literature review conducted within Chapter 2 identified that limited consideration had been given to the on-going performance management of DSTs. Specifically, it was unable to identify any approaches that address the challenge of managing the performance of DSTs used within an AM context.

Although, the literature identified a research gap that did not necessarily mean that a research challenge existed. If the performance of DSTs does not change (or if the performance change was always in a positive direction), there may be no industry need for approaches to manage DST performance. Chapter 3 details how an empirical study, involving expert practitioners, was used to confirm the existence of a research challenge.

Evaluation 2: Chapter 6 details the research undertaken to define the stakeholder requirements for the DST performance management approach. Within this study the outputs generated at each stage of the process of defining the requirements, were validated by two NGET subject matter experts.

Evaluation 3: Chapter 7 creates the DST Performance Management Process. Within this aspect of the research the ability of the process to meet the approach requirements was verified, and the logic/usability of the process were validated by two NGET subject matter experts.

Evaluation 4: Chapter 9 builds on previous evaluations. It increased both the scope of the enquiry, and the number of NGET experts involved. A focus group of five NGET subject matter experts was used to validate, verify and provide an overall evaluation of the research.

Evaluation 5: The approach had been created and evaluated by NGET. Within Chapter 10, the transferability of the approach to the water sector was evaluated by way of a semi-structured interview with an expert practitioner.

4.4.6 Ethics

When undertaking research actions should be taken to minimise harm to the participants (Bell, 2010; Denscombe, 2010a, b). That research complies with regulatory standards and is both ethical, and sustainable, is considered by Mårtensson *et al.* (2016) to be an important criteria for making assessments of the quality of the research that has been undertaken.

Although this research was not considered ethically sensitive, steps were taken to provide assurances to the participants. This included the signing of a research agreement, the use of participant informed consents protocols, and anonymising of participant input.

4.5 Chapter 4 – Summary Points

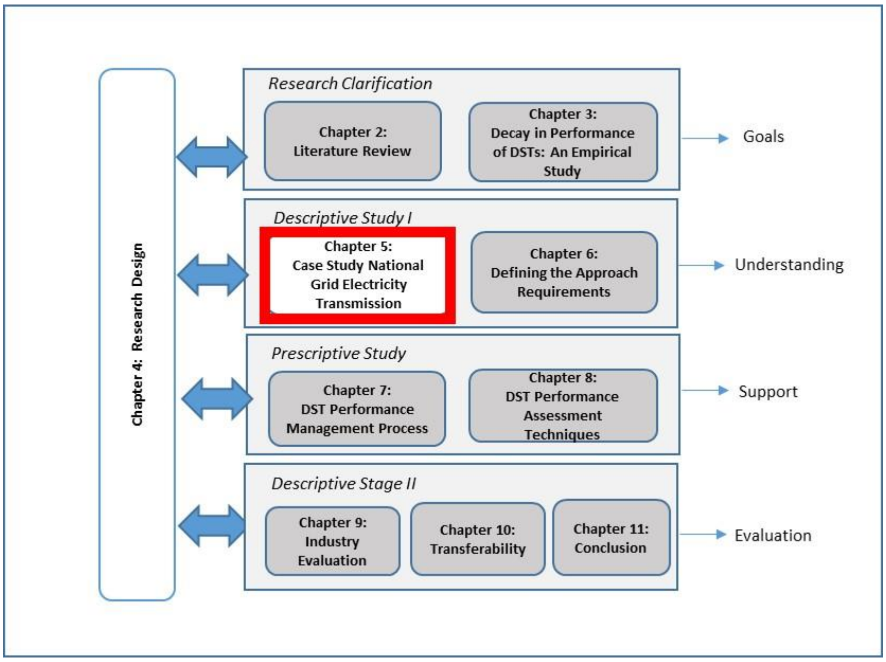
An overview of the research design is presented within Table 14.

Table 14. Research Design

DESIGN ELEMENT	DETAIL
Purpose (4.3)	
Aim	***To create a conceptual approach to manage the performance of decision support tools used within an Asset Management context.***
Research Objectives (RO)	RO1: *Understand research challenge context.* *RO2: Define approach requirements.* RO3: *Create a process for managing DST performance* RO4: *Create the techniques for applying the DST performance process.* RO5: *Evaluate the approach within the context of NGET.* RO6: *Evaluate the transferability of the approach to a wider AM population.*
Outputs	1. A conceptual DST Performance Management Process for use within an Asset Management context 2. DST Performance Assessment Techniques
Methodology (4.4)	
Philosophy (4.4.1)	Constructionist, interpretivism
Strategy (4.4.2)	Case Study – National Grid Electricity Transmission
Methods (4.4.3)	Qualitative, mixed methods Primary approach expert Input including interviews, questionnaires & focus groups
Analysis (4.4.4)	Qualitative
Evaluation (4.4.5)	Expert evaluation
Ethics (4.4.6)	Research agreement Informed consent Anonymised participant input

Table 14 shows that a case strategy was utilised within this research. The following Chapter presents the results of an in-depth exploratory study of the use and governance of DSTs within National Grid Electricity Transmission.

Chapter 5: Case Study National Grid Electricity Transmission



In creating a DST performance management approach having an understanding of how DSTs were used and managed within an actual infrastructure organisation was vital. To gain this contextual understanding a case study of National Grid Electricity Transmission (NGET) was conducted.

Within this Chapter, the approach used in conducting the case study is provided (5.1). The results of the study are presented. First, an introduction to NGET (5.2). Following, the organisation's use of DSTs is detailed (5.3) and three examples of DSTs currently used with the organisation presented (5.4). Control and governance of these example decision support tools is discussed (5.5). Finally, summary points highlighting the key findings are provided (5.6).

5.1 Case Study Approach

Within this research, a case study of NGET was used to create an understanding of how DSTs are used and managed within a key UK infrastructure organisation. This understanding was used to inform the design of the DST performance management approach which was created.

Gaining access to the information in order to conduct industrial case studies is often challenging. The funding under which this research was conducted afforded the researcher privileged access to the NGET organisation. This included access to restricted documents and NGET subject matter experts. Figure 20 shows the multiple input sources that were used in constructing the NGET case study.

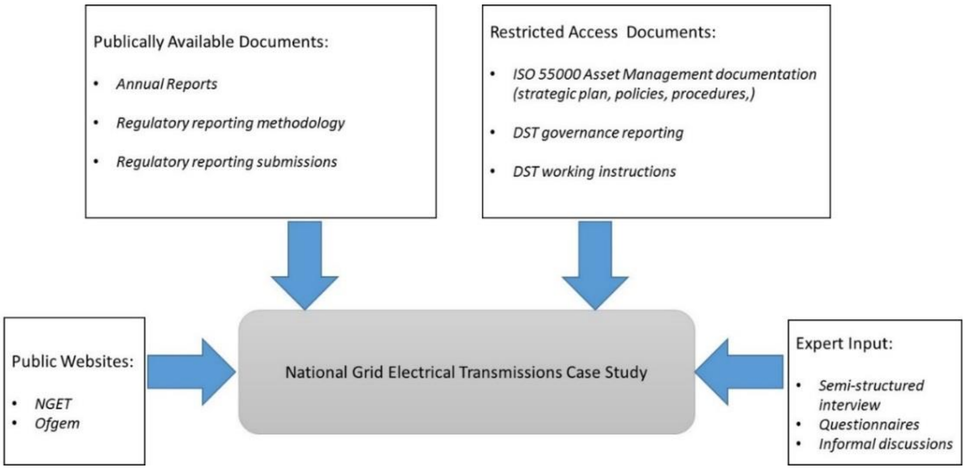


Figure 20. NGET case study input sources

Before looking at the detail of how DSTs are used within NGET, the study first focused on gaining a high-level understanding of the NGET organisation.

5.2 Introduction to National Grid Electricity Transmission

National Grid (NG) is a diverse organisation operating within the energy sector. It undertakes a number of activities, across a number of subsidiary companies and joint ventures (National Grid, 2015a). Figure 21 provides a simplified view of NGs business interests.

	UK Electricity	UK Gas	US Electricity	US Gas
Generation / Production			✓	
Transmission	✓	✓	✓	✓
Distribution		✓	✓	✓
Supply			✓	✓
System Services	✓	✓		✓
Other Interests		✓		✓

Figure 21. Simplification of National Grid plc business interests

The case study was undertaken within National Grid Electricity Transmission (NGET). NGET is one business area within the NG organisation. It plays a key role within the UK power infrastructure sector by both owning and operating the high-voltage electricity transmission network within England and Wales; and operating, but not owning, the Scottish transmissions network. This infrastructure comprises of the overhead lines, underground cables and substations which connect the power generators to the electricity distribution system (National Grid, undated). Figure 22 depicts where NGET fits within the UK electricity network.

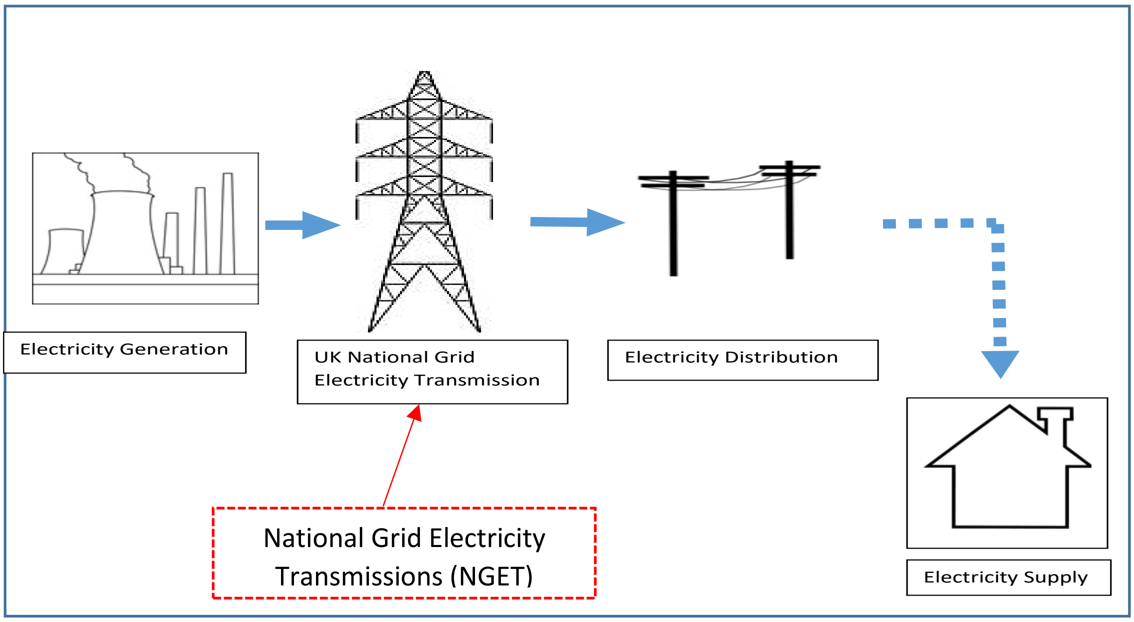


Figure 22. National Grid Electricity Transmission role within the UK electricity network

The nature of their business means that NG is rich in physical assets with a declared Regulated Asset Value (RAV) of £42.6 billion. This represents a 10% (£3.8 billion) increase on the previous year, and more than 25% growth (£8.9 billion) over the previous four years (National Grid, 2017b). The redesigning of the UK transmission network to support decarbonisation of the economy means that high levels of investment are set to continue. The Office of Gas and Electricity Markets (Ofgem), the UK energy regulator, estimate that £32 billion will need to be invested in UK energy networks between 2010-20; effectively doubling that spent during the previous 20 years (Ofgem, 2010).

Within NGET, this translates into capital expenditure in excess of £1 billion during 2016/17 (National Grid, 2014a); with a proposed £13.6 billion capital expenditure (Capex), £16.4 billion total expenditure (Totex) programme, over the eight years from 2013 (National Grid, 2012c). This expenditure programme, highlighted within Figure 23, will be financed by charging their customers. The level of this charge is regulated by Ofgem, under the RIIO pricing model (Ofgem, 2015).

Expenditure	
£3.8 bn	Annual increase on 2015/16 Regulated Asset Value
£32 bn	Estimated to be invested in UK energy networks 2010-20
£1 bn	Capex spend, National Grid Electricity Transmission 2016/17
£13.6 bn	Capex spend programme, National Grid Electricity Transmission, 2013-21
£16.4 bn	Totex spend programme, National Grid Electricity Transmission, 2013-21

Figure 23. National Grid, asset related financial expenditure

To manage this extensive asset base NGET has put in place an ISO 55001:2014 certified AM System. Although voluntary, having a certified AM system is strongly encouraged by the UK energy regulator, Ofgem (Ofgem, 2005). Therefore, within NGET ensuring that asset management practices align to the requirements and underpinning principles of the Standard is vital.

Under the ISO 5500x:2014 Asset Management Standard it is expected that there should be a clear line of sight between the objectives of the organisation and the asset management policies, plans and procedures (BS ISO 55000 Series: 2014). The objectives of NG are established through a hierarchy of documents that see their business Vision Statement translated into key performance indicators (KPIs). The Vision Statement sets the organisation’s high-level aspirations and intentions. This is underpinned by a Strategic Statement and Objectives that outline what they have to do to achieve this vision. Beneath this are financial and non-financial Key Performance Indicators, which the Board use to measure the Group performance. The objectives and KPIs of the organisation reflect the goals of NG. These goals are specific to NG rather than standardised across the sector, or across the other organisations who also operate in this area (i.e. SP Transmission Limited and Scottish Hydro Electric Transmission Limited).

A longitudinal comparison of NGs Strategic Objectives was undertaken. The results showed that for each of the reports from 2010/11 – 2012/13, the Strategic Objectives of NG evolve. From 2012/13, the objectives remain stable (Table 15).

Table 15. National Grid Strategic Objectives 2010/11 – 2016/17

Theme	Strategic Objectives 2010/2011 (National Grid, 2011a)	Strategic Objectives 2011/12 (National Grid, 2012b)	Strategic Objectives 2012/2013 - 2016/2017 (National Grid, 2013a, 2014c, 2015b, 2016, 2017b)
Policy	Positively shaping the energy and climate change agenda with our external stakeholders in both regions.		Engage externally: Work with external stakeholders to shape UK, EU and US energy policy.
Business growth	Expanding our capabilities and identifying new financeable opportunities to grow.	Balance and spread of businesses: Our blend of businesses generate cash to support dividends, and investment in assets to support equity growth and future revenues.	Drive growth: Grow our core businesses and develop future new business options.
Financial returns	Delivering strong, sustainable regulatory and long-term contracts with good returns.	Financial outperformance: We aim to maximise our returns within the constraints of our regulatory agreements, while continuing to invest for future growth.	
Environment and sustainability		Environmental responsibility: As a responsible business, we are committed to protecting the environment for current and future generations.	Embed sustainability: Integrate sustainability into our decision making to create value, preserve natural resources and respect the interests of our communities.
Efficiency & Innovation	Becoming more efficient through transforming our operating model and increasingly aligning our processes		Stimulate Innovation: Promote new ideas to work more efficiently and effectively.
Safety & reliability	Driving improvements in our safety, customer and operational performance.	Safety & reliability: Providing a safe and reliable network is our primary objective. It is what our customers expect.	Deliver operational excellence: Achieve world-class levels of safety, reliability, security and customer service.
Employee engagement / development	(1) Developing our talent, leadership skills and capabilities. (2) Building trust, transparency and an inclusive and engaged workforce.	People: Our people are the foundation of what we do. We are committed to developing our employees to the best of their abilities and attracting new talent from diverse backgrounds to meet the requirements of our business.	Engage our people: Create an inclusive, high-performance culture by developing all our employees.
Grid development	Modernising and extending our transmission and distribution network		
Stakeholder engagement		Stakeholder engagement: Stakeholders' views form an integral part of the way we do business and make decisions.	

The KPIs are the metrics used by the Board to measure group performance against the organisational objectives. They translate the objectives into criteria against which performance can be measured. Using information contained within NGs annual reports a table which compares the KPIs for the period 2010/11 – 2016/17 was created (Table 16).

Table 16. National Grid Key Performance Indicators 2010/11 – 2016/17

	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17
Financial KPI							
Total shareholder return	To increase	To increase	To increase				
Adjusted earnings per share	To increase	To increase	To increase	Not specified	54.7	59.2	62.5
Group return on equity	To increase	To increase	To increase	Not specified	13.7	13.3	11.6
Regulated controllable operating cost	To decrease	To decrease	To decrease				
Regulated asset growth				Not specified	To increase	Not specific. 5 – 7% growth	Not specific. 5 – 7% growth
Value added				Sustainably grow	Sustainably grow	Sustainably grow	Sustainably grow
Non-financial KPI							
Employee lost time injury frequency rate	Zero	Zero	Zero	0.15	0.15	0.1	0.1
Network reliability targets	99.9999	99.9999	99.9999	99.9999	99.9999	99.9999	99.9999
Employee engagement index	To increase	To increase	To increase	To increase	To increase	To increase	To increase
Customer Satisfaction (UK electricity transmission)				6.9	6.9	6.9	6.9
Greenhouse gas emissions	45% reduction by 2020 and 80% reduction by 2050	45% reduction by 2020 and 80% reduction by 2050	45% reduction by 2020 and 80% reduction by 2050	45% reduction by 2020 and 80% reduction by 2050	45% reduction by 2020 and 80% reduction by 2050	45% reduction by 2020 and 80% reduction by 2050	45% reduction by 2020 and 80% reduction by 2050
Workforce diversity					Not specific. Inclusive and diverse culture	Not specific. Inclusive and diverse culture	Not specified
Skill and capabilities						Not specific. Encourage young people in STEM	Not specific. Encourage young people in STEM
Community engagement & investment in education						Not specific. Create shared value for the communities	Not specified

The results showed that for the years 2010/11 – 2012/13 the KPi's were stable. However, since this time there have been a number of changes. Although some KPIs have remained unaltered (e.g. network reliabilty, and greenhouse gas emissions), some targets have been revised (e.g. adjusted earnings per share, and group return or equity), and new metrics introduced (e.g. skills and capabilities, and workforce diversity).

Comparing the change seen in the strategic objectives to that of the KPIs a difference is seen. During the period 2010/11 – 2012/13 the objectives change, but the KPIs remain stable. However, during the period 2012/13 - 2016/17 the objectives are stable, but the KPIs undergo small, but continuing change. The reasons for this disconnection are unclear but could include a desire to retain continuity, or differences in the speed at which change can be implemented. Whatever the reason, over time both objectives and KPIs are seen to evolve. Consequently, to ensure alignment between the NGET objectives and the asset decision choices over this period would require DSTs to adapt and evolve.

With a high-level understanding of the NGET, the case study progressed to identifying how DSTs were used within the organisation.

5.3 Decision Support Tools use within NGET

From informal communications with NGET subject matters experts, it was apparent that NGET made extensive use of DSTs to support asset decisions. Within NGET, they do not maintain a central register of all DSTs used within their business. This makes understanding the full extent of DSTs use challenging. Although no complete register was available, an inventory of "non- trivial" EUC (end user computing) reports and databases (DSTs utilising standard computer based software i.e. Excel/Access) was maintained (National Grid, 2017a).

The literature review had indicated that organisations would be using multiple DSTs within their business (Chapter 2, 2.2.2); the inventory demonstrated just how extensive DST use was. Analysis showed 195 different tools, being utilised across seven different business areas (Table 17). These DSTs were seen to have a range of types and purposes. For example within the asset integrity business area tools were used in connection with a number of assets including cables, transformers, switchgear, circuits, and were used to make decisions problems including identifying replacement priorities, criticality, and risk.

Table 17. National Grid Electricity Transmission. End User Computer systems.

Departments	Number
Operational Support	32
Business Assurance	18
Operations	3
Customer Services	2
Investment Management	25
Asset Integrity	89
Asset Policy	26
Total	195

Of the 195 DST identified within the inventory, 26 (13%) were identified by NGET as having a business criticality score of 4 (the highest score in a range of 1-4). This is significant as the literature suggested that as the criticality of the decisions increased, so the sophistication of the DST would increase. For NGET this was found not to be the case with Excel based DSTs in some cases being used to make highly critical decisions. Indeed, from the case study there was no obvious pattern between the DST type and the decision problem it was addressing.

Although showing extensive use of DSTs, it was recognised that the inventory provided only a partial picture as it did not include either manual or customised computerised DSTs. Informal conversations with NGET subject matter experts identified additional DSTs in use e.g. Have You Thought (HUT), a manual process used for selecting engineering options; the Whole Life Value Framework (WLVF), a manual process used to compare different asset investment and management options; the Natural Capital DST, an excel based DST used to incorporate natural assets and carbon; and the Salvo suite of DSTs, a customised computerised solution with a range of mainly financially focussed asset applications. Therefore, although exact numbers were uncertain, it was anticipated that in excess of 200 DSTs were in use. Furthermore, a significant proportion of these were created and/or were owned by people not employed in an IT role.

5.4 Example Decision Support Tools

As stated within the Research Design (Chapter 4, 4.4.2), the case study of NGET is used to inform the creation of the DST performance management approach, and NGET subject matter experts to evaluate its success (Chapter 9). The literature showed there to be a range of DST types, in order to evaluate the approach across the range, in conducting the evaluation the participants were asked to evaluate the logic and usability of the approach across three example DSTs. These example DST were:

- The Whole Life Value Framework – Manual DST
- Network Output Measures (NOMs) – Database / spreadsheet report DST
- Strategic Asset Management (SAM) – Customised Computerised DST

Selection of the example DSTs was based on three criteria: suitability, range, and practicality. First, the DSTs should be in current use within NGET AM operations. Second, they should represent each of the three types of DSTs commonly found within industry – manual, computer based spreadsheet / database, and customised computerised systems. Third, information for the DST should be accessible. Table 18 provides a summary of the key features of the three DSTs.

Table 18. *Key features of three example NGET DSTs*

Name	Type	Ownership	Purpose	Criticality	Use
Whole Life Value Framework (WLVF)	Manual	NGET	Support asset aquistion and management decisions	Unknown	Enterprise wide
Network Output Measures (NOMs)	Computer based spreadsheet / database report	NGET	Regulatory reporting on asset health and criticality	Criticality rating of 4 (highest of scale ranging from 1-4)	Restricted number of users < 20
Strategic Asset Managament (SAM)	Customised computerised system	'Service as a contract' with IBM	Manage asset condition and project asset maintenance spend	7 applications business critical 2 applications not business critical	Depends on application. Range of users from < 30 to more than >300

5.4.1 DST 1: The Whole Life Value Framework – Manual DST

The Whole Life Value Framework (WLVF) is a manual DST which is used to support decisions about what assets to acquire and how to manage them.

The WLVF is recognised by way of a policy document (National Grid, 2013b) within NGET's Asset Management System. As such it has organisational visibility, and both change authorisation and review are controlled (National Grid, 2014b). The WLVF was created during the period 2007-2009. Following creation there was a period of testing against current and historical asset decisions, culminating in a Version 1 launch June 2011 (Derrick Dunkley, 2015). Following implementation the Policy has undergone one minor revision with the current version being dated December 2013. A timeline for the WLVF is shown in Figure 24.

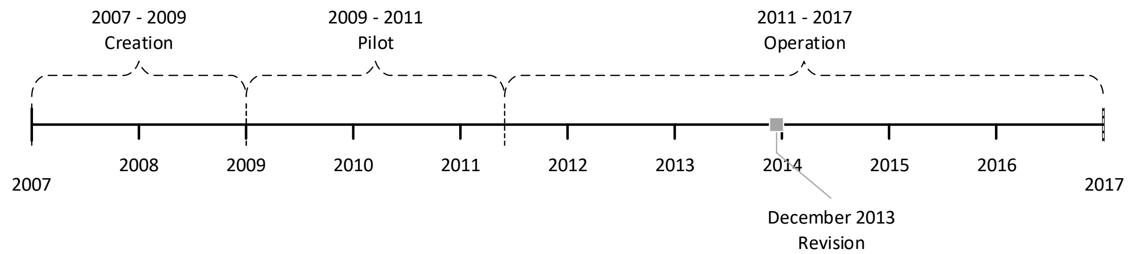


Figure 24. *Whole Life Value Framework timeline*

To understand how the WLVF was applied in practice the researcher observed a evaluation being undertaken (NGET WLVF Evaluation Meeting, 2015). The WLVF evaluation involved bringing together twelve NGET stakeholders, representing different parts of the business, as part of a facilitated meeting. During the four-hour meeting, three alternative fencing options were systematically assessed against seven themes:

1. Versatility
2. Sustainability
3. Safety by design
4. Asset ownership
5. Performance
6. Do-ability (Practicability)
7. System Access

The stakeholder inputs were captured and through group consensus, each of the assets awarded a rating that ranged from A (high), to E (low), against each of the seven themes. Figure 25 shows the comments captured during the evaluation under the *versatility* theme of the WLVF.

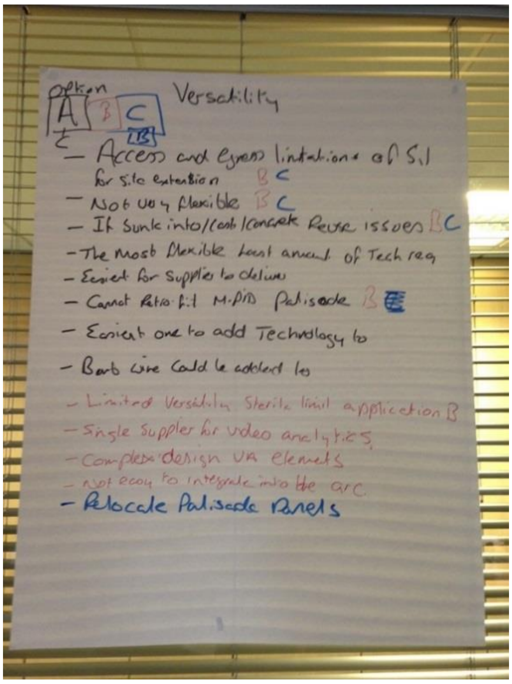


Figure 25. WLVF Evaluation: comments captured under versatility theme

The output of the meeting was a WLVF evaluation report. The report was produced by way of an Excel template and contained both qualitative and quantitative data, represented in graphical and verbatim form. This included: a basic project overview and details of the project team; a comparison of the Totex cost of the various options; a 'whole life value' visualisation for the options; and a recommendation supported by pros and cons (National Grid, 2015c).

Figure 26 presents an example 'whole life value' visualisation found with the WLVF evaluation. In this example three options (A - C) are compared across the seven themes. The positioning on the radar diagram represents the rating give to each option (for each of the themes) with the lowest E rating being closest to the centre, and the highest A rating furthest away.

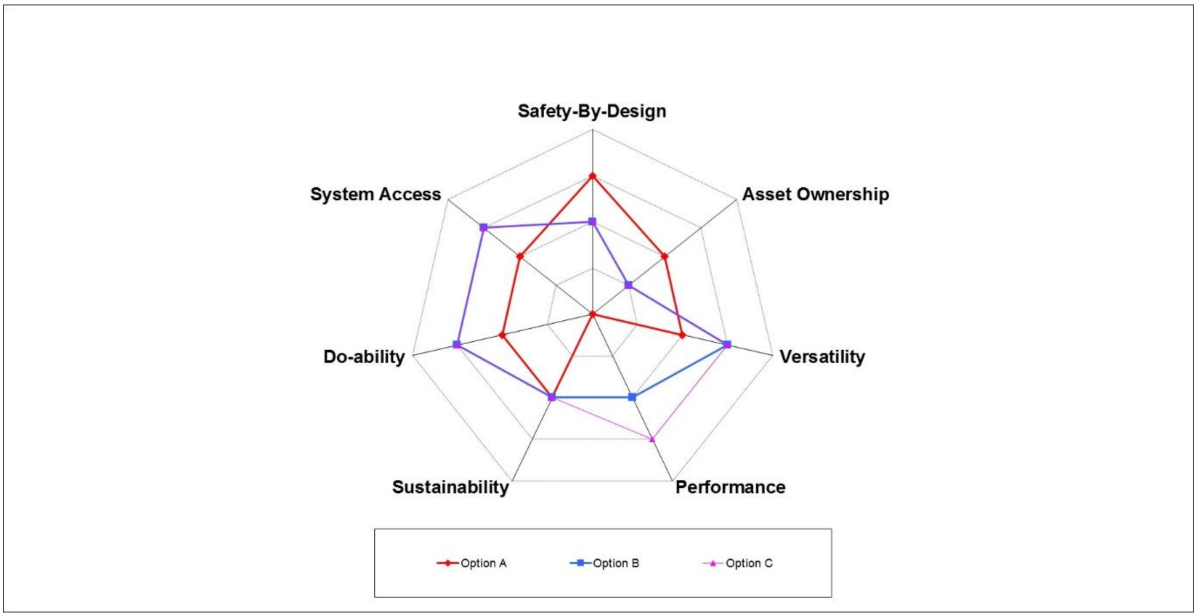


Figure 26. Example WLVF visualisation

The WLVF evaluation was produced by the meeting facilitator and was forwarded for use by decision makers within an Investment Committee meeting. Therefore, in this specific case those who created the evaluation report, and those making the decision, were different.

Although the WLVF is intended to be an enterprise wide DST, used by a range of people and applied to a range of decision problems, its use is voluntary and it is intended that it is only used when it adds benefit (National Grid, 2014a). The extent of its actual use within NGET was difficult to establish. Completed WLVF evaluations should be retained as part of the organisation's AM system documented information. In an attempt to understand the number of WLVF evaluations that were being undertaken an analysis of the retained evaluations was conducted. Figure 27 shows the number of WLVF evaluations by year.

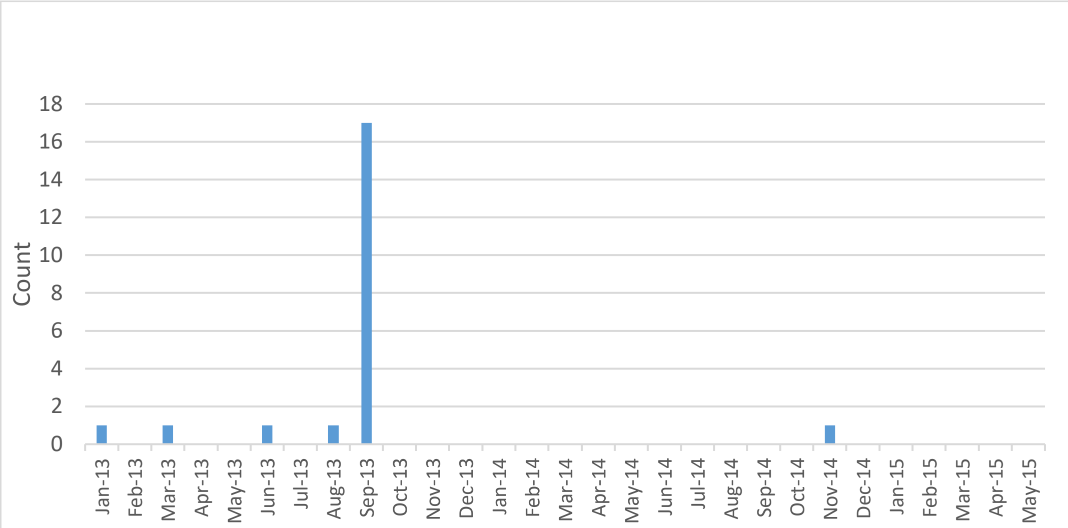


Figure 27. Analysis of WLVF evaluation issue dates

The results of this analysis suggested that the WLVF tool had only ever been used sporadically, and prior to the latest evaluation not since 2014. The reason for such a result could be that evaluations only offer occasional value and as such are infrequently conducted, or that evaluations do offer value, but their use is not embedded in the organisation. Alternatively, it could simply be a case that the WLVF is being used but the evaluations are not being retained.

5.4.2 DST 2: Network Output Measures –Database/Spreadsheet DST

Within the UK, NGET operate as regulated business that is subject to pricing control. The current pricing model, RIIO-T1, runs for the period 2013-2021. At the start of this period NGET were required to make a submission, which considered four areas: Network Asset Condition, Network Risk, Network Performance, and Network Capability. Using these four measures the submission (made in March 2012 for the period 2013-2021) outlined the development, maintenance, and operation of the Network and assessed future network expenditure.

Figure 28 reproduces an illustration taken from the NOMs Methodology. To arrive at the capital investment plan the methodology combine inputs of asset health (asset health priorities), with the risk (replacement priorities), together with performance/capability data (scheme priorities). The capital needed is raised by a charge placed on NGs business and private customers.

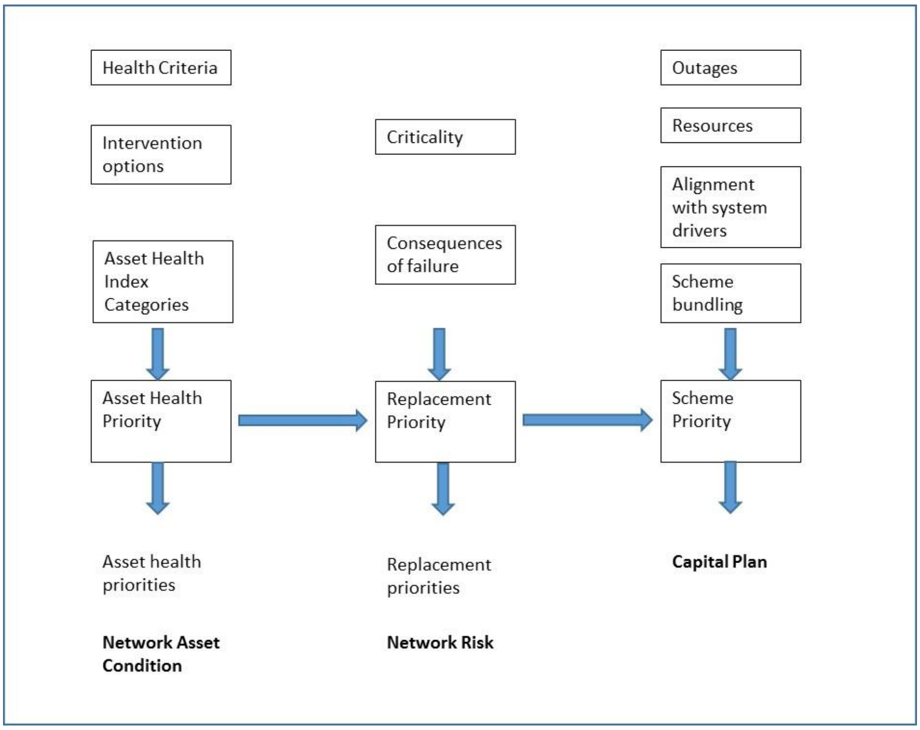


Figure 28. Network expenditure requirements (National Grid, 2010)

The Network Output Measures (NOMs) is a spreadsheet based DST. It was used in preparing the RIIO-T1 submission, and in subsequent annually to report to regulators on the current health and criticality of key assets within the transmissions network. Therefore, unlike the WLVF, it has a specific function and its use is mandatory, rather than voluntary.

In order to fully understand the NOMs DST, the researcher was given access to the NGET subject matter expert in charge of compiling the 2017 submission, and the work instructions for the NOMs process (National Grid, 2017c).

The NOMs tool has five models (underground cables, overhead lines, reactors, switchgear, and transformers). The five models were created in 2010 and were first used in preparing the 2012 RIIO-T1 submission. The models work on the same basis, and with the exception of a change to the degradation curve for overhead lines made in 2010, have been unaltered since first introduced (Figure 29).

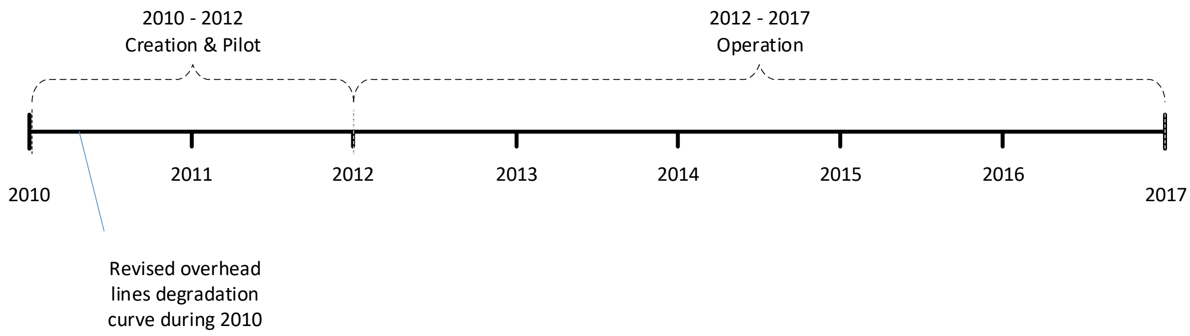


Figure 29. Network Output Measures DST Timeline

These five models were created and are maintained/updated by asset operations within NGET. The NOMs tool takes NGET data and combines it within the models in order to generate a report. Therefore, all data and the maintenance/updating of the models is contained within the NGET asset operations area.

The NOMs report is submitted to Ofgem annually. Dependent on the result there can be either financial benefit or penalty for NGET. If NGET has introduced innovation which has resulted in the health of the assets declining at a lesser rate (and thus requiring less maintenance / replacement) the organisation is able to retain some of money which was allocated to them for conducting maintenance. However, if the report shows that the health of the assets has declined below an acceptable level, NGET are expected to bear some of the financial cost of increased maintenance actions. Consequently, the performance of the NOMs DST in both predicting and reporting asset health can have significant financial implications for the business.

Although the expert considered that the NOMs models produced accurate reports, the process of creating the reports was both complicated and labour intensive.

5.4.3 DST 3: Strategic Asset Management (SAM) – Customised Computerised DST

SAM is a web based computerised system that is used within NGET to assist in managing asset condition and project spend. It provides access to a range of data and, through user interfaces and applications, allows the monitoring of assets on-line and in near 'real-time' (National Grid, 2014d).

The creation and piloting of SAM took place during from 2010 -2013. Phase 1 of the operational system ran from 2013-2015. Phase two, which increased functionality, running from 2015 (Figure 30).

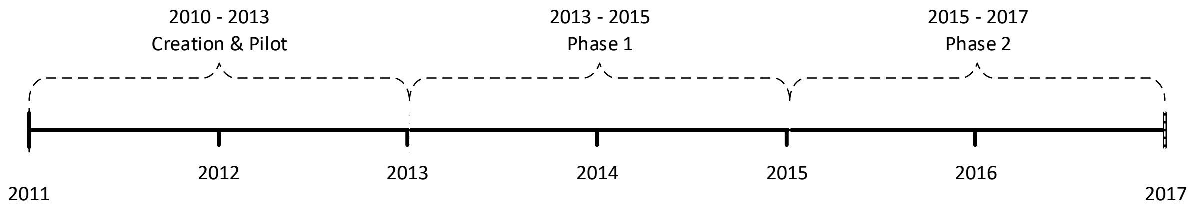


Figure 30. Strategic Asset Management (SAM) timeline

The purpose of SAM was to bring standardisation to the capture, storage and use of data, resulting in higher reliability, and environmental and safety outcomes. Unlike the WLVF and the NOMs DSTs, where costs were minimal and mainly comprised of employee time, creating and implementing SAM required capital expenditure in excess of £20 million (National Grid, 2012a). This level of investment means that SAM was high profile both within and outside of the business.

The business case for this level of investment was that it would deliver attributable benefits in the region of ~£13 million between 2013-2021 (National Grid, 2011b), provide a platform enabling innovation, and clear reporting to stakeholders and customers (National Grid, 2012a). The main benefit claims for SAM were:

- **Real-time, interactive management of assets**: the move towards a risk and criticality replacement and maintenance strategy required real-time condition and capability data for assets.
- **Dynamic network monitoring and control**: to achieve the UK climate change target increasingly electricity load needs to be controlled to optimise the level taken from renewable energy sources.
- **Leveraging greater benefit from existing processes and systems**: increased efficiency of staff by reducing the need to source and manipulate data from a vast number of sources.
- **Utilising new and sophisticated condition monitoring equipment:** new sensors and monitoring systems move from information from qualitative to quantitative data.

A simplification of the SAM configuration is shown in Figure 31. This shows how multiple data sources feed into models, which can then be interrogated by way of a user interface.

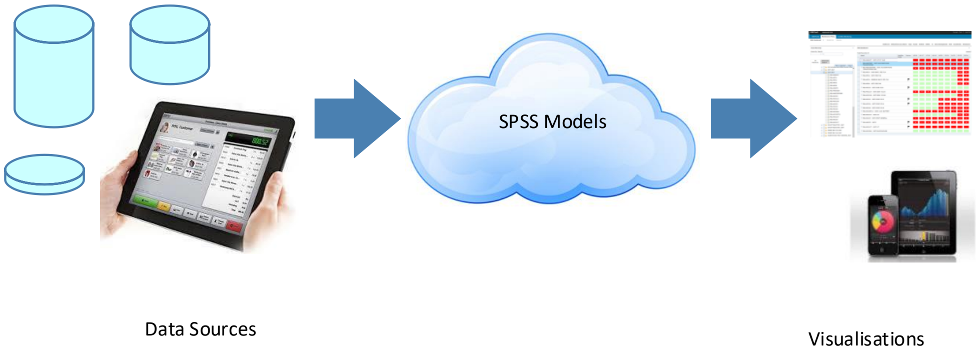


Figure 31. Strategic Asset Management (SAM) configuration

The data that feeds into SAM comes from both within NGET and external sources. For example, the NGET field engineers conduct quarterly surveys and input various condition data (e.g. thermal, radio frequency, and partial discharge) into their handheld devices. In this case, the data is both generated and managed within NGET. Alternatively, the data can come from external sources over which NGET has no data management authority or responsibility. For example, weather data from the Met Office.

The data is used to populate models. These models are held on the Cloud and provided under a 'software as a service' contract – that is, they are used but not owned by NGET. Although NGET have access to the SPSS (statistical software) reports, the models are created and updated by IBM. Visualisations using these models are run across the organisation. In some cases, visualisations will be directly utilised by the user; whilst in others, the user acts as an intermediary providing information for a remote decision maker(s).

As at July 2015, SAM had nine functioning applications. Of these nine, seven are considered to be "business critical" (National Grid, 2017d). The discovery that two applications were not business critical supports that there is not necessarily a correlation between cost of the DST and the criticality of the tool to the business.

5.5 DST Control and Governance

The three examples demonstrate that there are DSTs used within NGET where their performance will have significant implications for the business. Given this, it raised the question of what activites are undertaken to ensure their performance.

The case study provided evidence that DST control and governance activities were undertaken within NGET. The WLVF, is recognised as a policy document within the AM System and as such it would be subject to a scheduled performance assessment. However, review is only scheduled to take place every eight years, and as identifed within the literature the need for decision systems to adapt is likely to require more immediate attention (Courbon, 1996; Sprague, 1980).

For DSTs which are not recognised by either an AM policy or procedure, control and governance is not coorodinated by way of an AM process. Rather, activities follow a process which is outside of the AM system – as is the case of the inventory of computer based spreadsheet / database DSTs – or are undertaken in response to, or as part of another item of work. For example, as a follow up to the introduction of SAM a benefit realisation study was undertaken (National Grid, 2017d).

The inventory of standard computer software based databases/spreadsheets was the primary systematic activity of DST governance within NGET. The inventory includes all 'non-trivial' spreadsheets or databases used within each AM department. An individual within each team is given responsibility for ensuring that the inventory is maintained and it should be periodically reviewed (at least annually, but more frequently where there are staff changes).

The inventory has seven fields:

- Contact name: Responsible person
- Report: Spreadsheet / Database File name
- Department: NGET department name
- Team: NGET team name
- Category: A description of what the report is used for
- Criticality: Rating based on the use of the database or spreadsheet (1-4)
- Likelihood: Combination of number of users and complexity (1-4)

The inventory improves DST visibility / ownership, and through the application of a criticality rating, identifies those DSTs which have greater importance to the business. Although having value, the inventory has limitations.

As it does not extend to include manual, or customised computerised systems, neither the WLVF or SAM DSTs are included. This is despite seven of the nine SAM applications being considered as 'business critical'. In this way it provides only a partial picture of the DSTs used within the organisation.

Within the inventory the assessment of the 'criticality' of a DST is based on the report type, rather than the potential or actual value the DST contributes towards achieving the organisational objectives. If DSTs are considered to be assets, then under ISO 5500x:2014 there should be a clear line of sight between the organisational objectives and assessment of their criticality. The lack of a standard method through which the criticality of a DST can be assessed has resulted in inconsistency across the NGET DST governance activities. Whereas, the inventory uses a 'criticality rating' of between 1 and 4 (4 being the highest risk), within the benefit realisation work conducted for SAM there are only two classifications: 'Business Critical' and 'Not Business Critical'. This means that comparisons of criticality across DST types would not be possible.

Finally, the inventory is limited to identifying DSTs used within NGET. It does not attempt to assess the perfomance of these DSTs. In this way although the NOMs tool is identified, and the criticality of the tool assessed as being at the highest level (4), the register does not form part of a broader process which provides assurance of the performance of that tool. That is, as part of this process it does not assess whether this business critical tool is 'fit for purpose'.

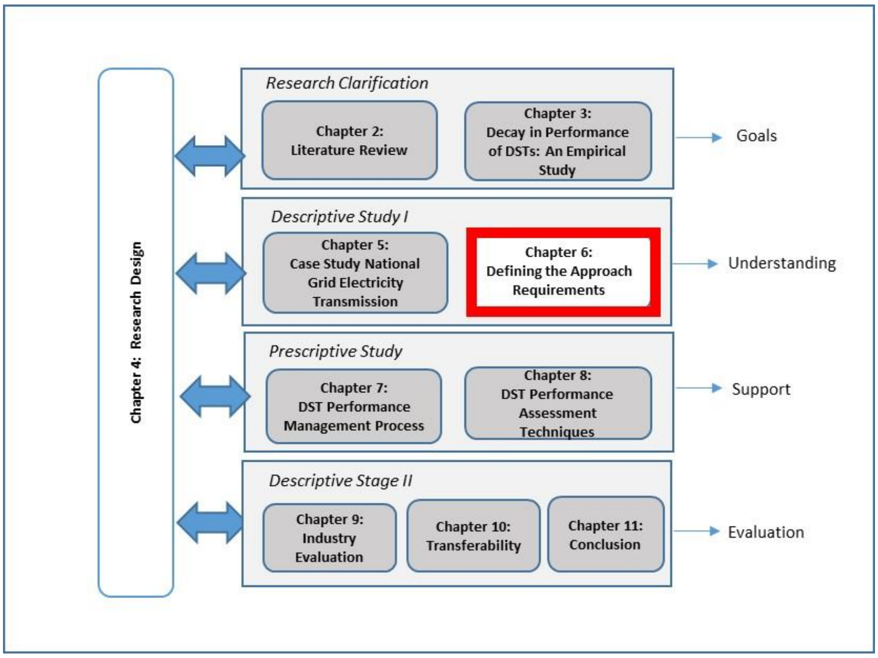
On the other hand the benefit realisation work does consider the performance of the SAM tool. However, SAM's performance is considered in isolation and is restricted to making a financial comparison against the benefits it is considered to deliver, against the benefits it was projected to deliver. It does not specifically consider user or decision maker satisfaction with the tool as part of this review.

5.6 Chapter 5 – Summary Points

- NGET make extensive use of DSTs with in excess of 200 tools used across seven different business areas.
- Within NGET there is no complete inventory of all DSTs used in making asset decisions.
- Of the computer based database / spreadsheet DSTs, ~13% were assessed at the highest critical rating level.
- The cost of creating a DST does not necessarily correlate to business criticality.
- There is inconsistent assessment of criticality across DST types.
- Criticality of the DST does not align to value the tool contributes towards achievement of organisational objectives.
- Within NGET, DSTs control and governance activities are undertaken. However, there is no systematic process for measuring and monitoring performance.

The case study provides understanding of how DSTs were used and governed within NGET. Chapter 6 builds on this work by defining the requirements of an approach for managing DST performance within that context.

Chapter 6: Defining the Approach Requirements



Key to designing an approach for managing DST performance to be used within industry was understanding their requirements for such an approach. Chapter 6 details the research undertaken to generate that understanding.

The Chapter is structured as follows. First, by way of an introduction, a background to requirements engineering (RE) is presented (6.1). Next, the four-stage approach used within this study is detailed (6.2): Elicitation (6.2.1), Analysis (6.2.2), Documentation (6.2.3), and Validation (6.2.4). The results are presented and discussed (6.3). Finally, summary points highlighting the key findings are provided (6.4).

6.1 Requirements Engineering

It is generally accepted that the success of projects will be largely dependent on having a clear understanding of business, user, and system requirements. Historic estimates have suggested that problems resulting from poor requirements activities were responsible for between 25-50% of systems engineering projects not meeting performance criteria (Austin, 2006). Indeed, in 1995 an influential US report identified incomplete requirements as the primary factor why information technology projects were impaired and ultimately cancelled (The Standish Group Report, 2014). Requirements Engineering (RE) aims to address this challenge. Used predominately in the field of systems development, the widely cited definition of RE is:

“The branch of software engineering concerned with the real-world goals for, functions of, and constraints on software systems. It is also concerned with the relationship between these factors to precise specification to software behaviour, and to their co evolution over time and across software families” (Zave, 1997).

Put simply, RE is a collection of best practices for managing requirements and constraints and translating the wants and needs of the stakeholders into a detailed statement of how the system should be.

The discipline of RE draws on a number of fields including sociology, psychology and linguistics. The result is a multitude of approaches and complex underpinning theories. However, in practical application four key activities are generally seen:

- *Elicitation* involves the systematic seeking, uncovering, and acquiring of requirements.
- *Analysis* the requirements collected during elicitation are analysed in order to identify problems of missing, conflicting, and inconsistent requirements. Where conflicts are seen, or where the requirements exceed what can reasonably be delivered within the constraints of the project, prioritisation/negotiation will be required.
- *Documentation* involves the recording of agreed criteria that the system must meet in order to be considered ‘successful’. These can be either written in the natural language of the stakeholder, a more technical description of what the system should provide and constraints on its development, or both.
- V*alidation* is the stage at which the documented requirements are evaluated to test that they satisfy the customer. Validation is an important step as it identifies any issues that might have arisen when identifying, analysing and documenting requirements (Dick *et al.*, 2017; Jiao, 2006; Parvianen and Tihinen, 2007; Sommerville and Sawyer, 1997; Zowghi and Coulin, 2005).

Figure 32 depicts an early approach proposed for use within systems development (Sommerville and Sawyer, 1997). It shows RE to be an iterative, but linear process. The inputs to the process include user needs, system information, and constraints (regulations and standards). The inputs are the basis from which requirements are identified. The requirements are analysed to identify missing and conflicting requirements. Where conflicts are seen negotiation is undertaken. The outputs of the analysis stage are documented and translated into formal agreements (requirements documents, systems specification, or both), which are then validated by the customer.

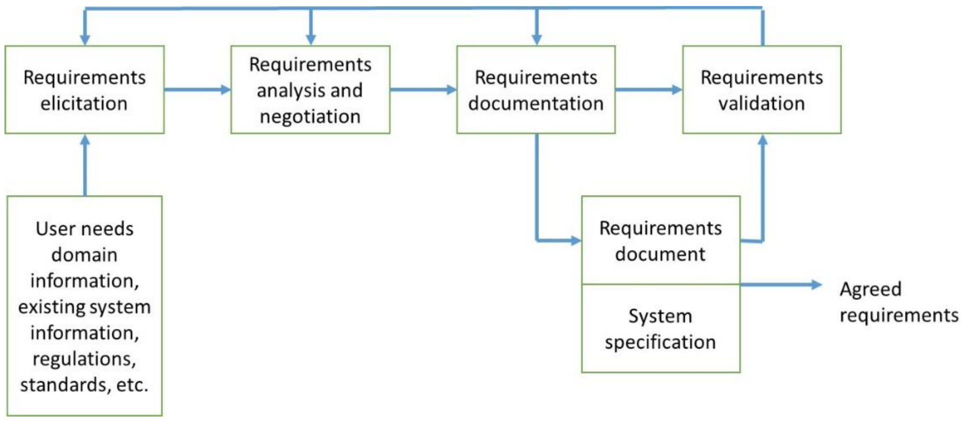


Figure 32. Requirements Engineering process (Sommerville and Sawyer, 1997).

Parvianen and Tihinen (2007) identify that is very difficult to create a linear sequence of events that take place within RE (Figure 33). Although, not following sequential steps the same four activities take place whereby the requirements and constraints are gathered, analysed in order to identify detailed system requirements, documented and validated. What the Parvianen and Tihinen (2007) process identifies, which is not specifically highlighted by Sommerville and Sawyer (1997), is that requirements evolve and as such there will be a need for requirement management.

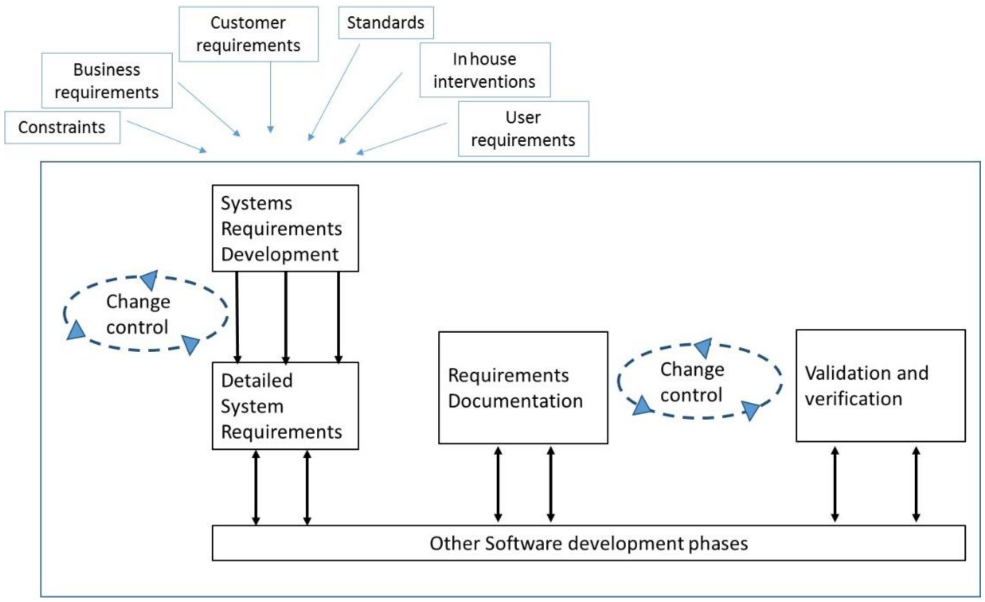


Figure 33. Requirements Engineering process (Parvianen and Tihinen, 2007)

Although the Sommerville and Sawyer (1997) and Parvianen and Tihinen (2007) illustrations show there to be both stakeholder requirements and requirements for the system, the relationship between the two is not obvious. Dick et al. (2017) propose that requirements types fall into different layers. There are stakeholder requirements, and system requirements, which flow through to an architectural design. These requirements layers can be associated with either defining the problem (problem domain), or the solution (solution domain) (Table 19). They assert that early in the design process there is a need to understand the problem domain, but that that this should be no more than is required to define the space. This allows the system engineers the freedom to define the solution without pre-conceived ideas.

Table 19. Levels of requirements in system engineering context

Requirements layer	Domain	Role
Stakeholder Requirements	Problem domain	State what the stakeholders want to achieve through the use of the system. Avoid reference to any particular solution.
System Requirements	Solution Domain	State abstractly what the system will do to meet the stakeholder requirements. Avoid reference to any particular design.
Architectural Design	Solution Doman	State how the specific design will meet the system requirements

Although principally used within systems development, RE is sometimes seen used in other areas for example product development (Jiao, 2006), healthcare (Kossmann, 2014), and architecture (Bonenberg, 2018). Indeed, Callele *et al.* (2017) consider that RE can be applied to many (if not all) disciplines. The generic process they create shows RE as an iterative cycle that can be used to generate a problem statement, or a problem statement and a requirement specification (Figure 34).

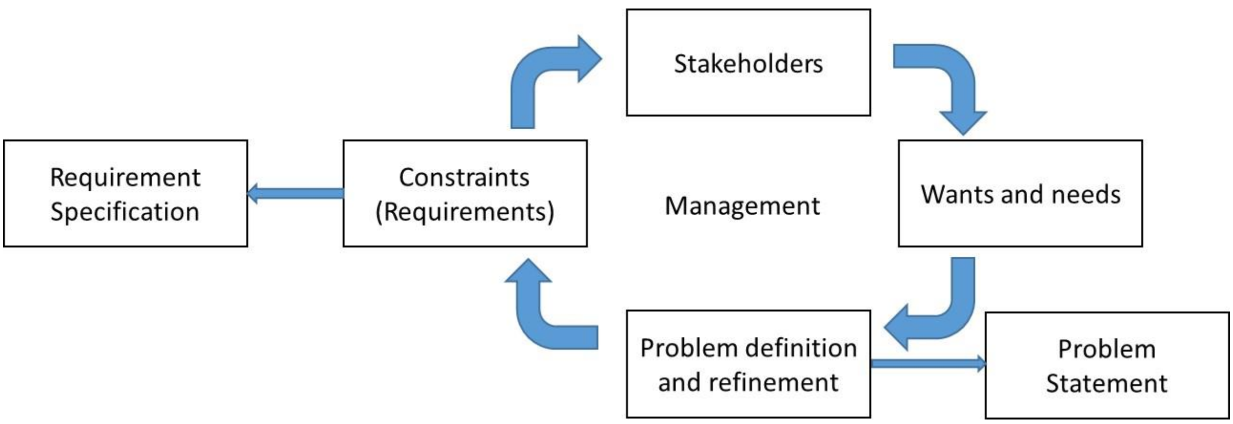


Figure 34. Generic Requirement Engineering process (Callele et al., 2017)

Comparing the generic process presented by Callele *et al.* (2017) to the IS version presented by Sommerville and Sawyer (1997) and Parvianen and Tihinen (2007) there is little novelty in the activities which will be undertaken. Application of the process will still require elicitation and analysis of requirements, documentation, and validation.

6.2 Defining the approach requirements

The purpose of this study was to define an initial set of requirements that would be used to inform the design of a prototype approach for managing DST performance. The intention was that the approach would provide a catalyst for stakeholder discussion, which would cause requirements to emerge and crystallise. Therefore, the expectation was that RE would be cyclical and conducted at each stage of progressing the approach through to industry adoption.

Figure 35 presents the process used within this study. Based on the cyclical process by Callele *et al.* (2017), it has been annotated to show how it aligns to the four generally seen RE stages (elicitation, analysis, documentation and validation) .

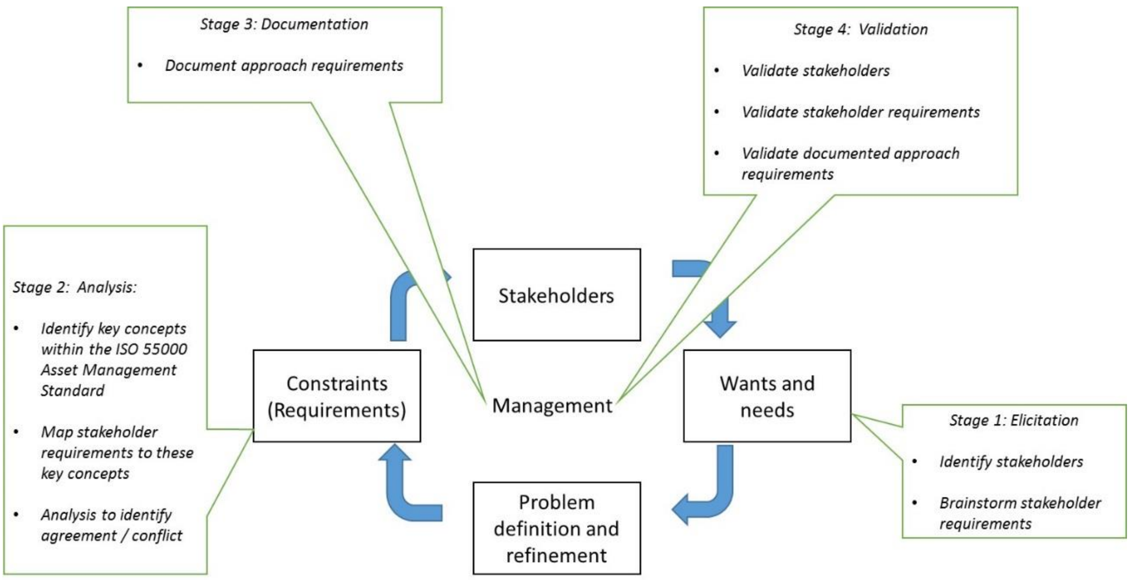


Figure 35. Requirement Engineering process

6.2.1 Stage 1: Elicitation

To identify stakeholder requirements an elicitation exercise was undertaken with a NGET subject matter expert. This involved two stages. First, the expert was asked to identify the stakeholders. Second, to brainstorm the requirements of these stakeholders.

In this study obtaining input from a single subject matter expert was considered preferential. In practice, at this early stage of the research recruiting participants from each of the stakeholder groups, ensuring that they had an appropriate level of understanding of the use of DST in making asset decisions, and making judgements as to the relative importance of their views, added unnecessary complexity. This research adopted an evolutionary research pathway (figure 17). The intention is that RE studies conducted at later stages of the research will expand the number and range of stakeholder participation.

Although considered preferential, there are inherent risks to using one source to identify all stakeholder requirements. To mitigate against stakeholders and their requirements being missed a systematic approach was taken. First, the expert was asked to identify the approach stakeholders against a theoretical map. They were then asked individually to brainstorm the requirements of each.

The use of a stakeholder map to identify stakeholders is proposed within the work of Callele *et al.* (2017). Many stakeholder maps, hierarchies and taxonomies are available (Alexander, 2005), within this study the seminal Freeman model is used (Figure 36). The justification for selecting the Freeman model was that it was both clear, offered an appropriate level of granularity, and despite being created more than 30 years remained relevant.

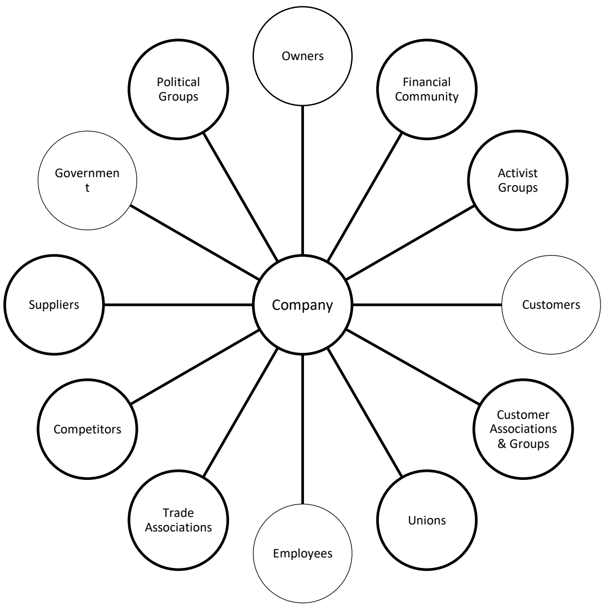


Figure 36. Stakeholder map (Freeman, 1984)

In identifying the requirements of each of the stakeholders, a number of techniques might have been used. Table 20 shows a sample of common approaches. In this case, brainstorming was considered preferential to the other approaches. First, the requirements were generated by a subject matter expert rather than the researcher who is less familiar with the environment. Second, it promoted freethinking. That is, with the pace of brainstorming and by removing the need to justify statements, more requirements might be uncovered. Third, being conducted without researcher intervention removed any influence they might have over the requirements that were generated.

Table 20. Sample elicitation techniques (Zowghi and Coulin, 2005)

Technique	Description
Interviews	Probably the most frequently used technique. Can include structured, semi-structure and unstructured approaches. The usefulness of the results will depend greatly on the skill of the interviewer.
Questionnaires	Mainly used during the early stages of requirements elicitation. To be effective the terms, concepts and boundaries of the domain must be well understood.
Task Analysis	Top-down approach where high-level tasks are de-composed into subtasks and eventually detailed sequences until all actions and events are described. Generally time consuming and takes considerable effort.
Introspection	Requirements are based on the analyst believes the stakeholders want and need. Often used as a starting point for other requirements elicitation exercises. Success is dependent on the analyst being very familiar with the environment.
Brainstorming	Participants rapidly generate as many ideas as possible. Process promotes freethinking.

6.2.2 Stage 2: Analysis

Both the literature review (Chapter 2) and the NGET case study (Chapter 5), identified the importance of aligning the DST performance approach with the ISO 5500x:2014 Asset Management Standard. Complying with the Standard was therefore a constraint on the design of the final approach. During analysis, the needs and wants of the stakeholders were cross-referenced against key concepts underpinning the AM Standard, as a means of identifying any missing or conflicting requirements.

Figure 37 details the three steps undertaken within the analysis. Step 1: NVivo CAQDAS (Computer Assisted Qualitative Data Analysis Software) was used to uncover key concepts within the ISO 5500x:2014 Standard. Step 2 the stakeholder wants and needs were mapped to the key concepts. Step 3 the results were analysed to see where there was agreement and/or conflict.

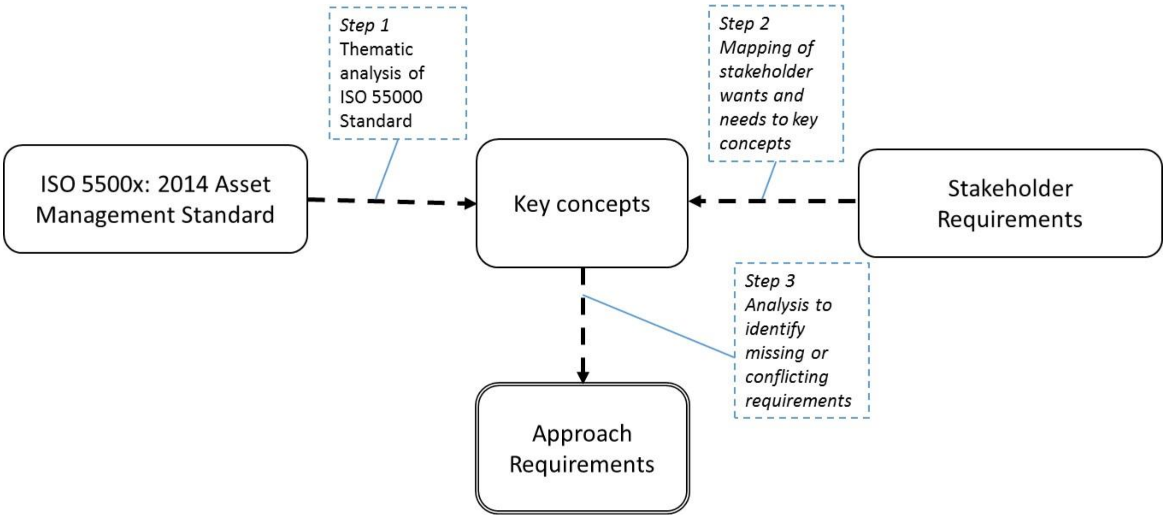


Figure 37. Approach used in analysis of requirements

6.2.3 Step 3: Documentation

The output of the analysis was used to document the approach requirements.

6.2.4 Step 4: Validation

Within the Research Design (Chapter 4), the five stage research evaluation plan was presented (Figure 19). The validation conducted within this study represents stage 2 within this plan. Stage 2 validates the research undertaken in defining the approach requirements with a small number of significant NGET stakeholders.

Validation was conducted by way of a focus group involving two subject specific experts. A focus group is a commonly used research technique in which participants are brought together to explore an idea. The use of a focus group was considered preferable to separate interviews. First, it ensured that both participants were exposed to identical information about the research. Second, it was anticipated that in giving the participants the opportunity to discuss would result in a more in-depth exploration.

Although there is no ideal focus group size, traditionally there would be between six to tweleve participants (Bell, 2010; Denscombe, 2010a; Gray, 2014). More recently however, the use of mini focus groups of between two and five people have emerged. Mini focus groups have been found to be particularly useful in situations where recruitment is difficult, or where the intensity of the discussions means that having less participants would be preferential (Feltwell and Rees, 2004; Githaiga, 2017; Taylor *et al.*, 2016). Within this research the availablity of subject matter experts was limited (Chapter 4, 4.2) , therefore the use of mini focus groups offered a practical and attractive approach.

The two subject matter experts were selected by their NGET departmental managers. Both were employed within NGETs Process and Enablement area but belonged to different departments, and had different job roles. Whereas one was directly involved with the creation of DSTs, the other had a business analytics role. Obtaining validation from these two both perspectives was considered important, as was identified within the literature, the life cycle management of decision systems will involve interactions between those who build, and those who use the systems (Keen, 1980).

The validation questions considered the outputs at each stage of the research. Designing the questions in this systematic way was intended to encourage logical thinking. For example, should the questioning identify a new stakeholder, the participants would then be stimulated to consider whether the requirements of that stakeholder had been captured.

The specific areas addressed within the validation were:

1. Were the stakeholders valid? Had all stakeholders been taken into account? Were there any stakeholders who should not have been included?

2. Were the stakeholder requirements valid? Had the brainstorming exercise captured all the requirements of stakeholders? Were there any requirements that should not have been included?

3. Were the approach requirements valid? In defining the approach requirements, had the important elements been captured?

During the focus group the participants were free to ask questions and discuss their views. Following, the participants were asked individually to complete a questionnaire (Appendix B). The use of individual questionnaires allowed the participants to express their own view. This was considered important, as although it was envisaged that future research would require progression towards a group consensus, at this early stage understanding the perspectives of each individual was important.

6.3 Results of the Requirement Engineering exercise

The results of the RE exercise follow. To ease understanding they are presented to reflect the four stages undertaken within the study.

6.3.1 Elicitation results

During the elicitation stage, the Freeman (1984) stakeholder map was used to identify the approach stakeholders. Four stakeholders were identified: owners (NG and NGET), customers (private and business), employees, and government (Ofgem). At this stage of the research, it was not considered necessary to pursue more granularity of stakeholders (i.e. which specific employees).

Following, the NGET subject matter expert was asked to brainstorm the requirements of these stakeholders in turn. The brainstorming exercise generated 14 requirements statements. Although the wording of the statements were individual, common terms and themes emerged. For example that the approach be '*agile'* and '*safe',* and '*we know how it works',* it is '*easy to understand'* (Table 21).

Table 21. Requirements of a DST performance management approach by stakeholder

Stakeholder	Recognised party	Requirement
Owner	National Grid NGET	• Life-cycle value achieving customer requirements and over delivery of regulatory performance • Industry compliant conforms to ISO 55000 and ISO 31000 • Adaptable to asset base, satisfies data requirements and organisation systems • Performance to be agile. Accurate tool that produces validated results • Technical competence reflecting asset position and network risk
Customers	Private Business	• Life-cycle management, safe, credible, economic and efficient. • Value, safe environmentally. Adhering to International Standard
Employees	All National Grid employees within the electricity transmission area	• Delivers credible results • Agile can be upgraded • We know how it works • Safe, reliable, and efficient outputs which are understood
Government	Ofgem	• Consistent with consumer value mechanistic approach easy to understand translating inputs, process, outputs. • Transparent, consistent with Scots TO's • Stable – repeatable and reproducible

One of the themes that emerged was that the approach should conform to the International Standards. This was identified as a requirement of both customers and NG / NGET (vignette 3 & 4):

Vignette 3. NG/NGET: "Industry compliant conforms to ISO 55000 and ISO 31000"

Vignette 4. Customers: "Value, safe environmentally. Adhering to International Standard"

The importance of the approach aligning with the AM Standard supported the conclusions of both the literature review and the NGET case study that this was a constraint on the design of the approach.

6.3.2 Analysis Results

As detailed, validation of the requirements was undertaken in three steps. First, key concepts within ISO AM Standard were identified. These are fundamental principles, and general requirements for AM activities that constrain how the approach should be designed. Second, the stakeholder comments were mapped to these key concepts. Third, the results were analysed to identify where agreements and inconsistencies existed.

Step 1: Identify key concepts within the fundamentals of the ISO 5500x:2014 Standard

An initial examination of the suite of Asset Management Standard documents identified that there are no specific requirements for a DST performance management approach. Rather, there are principles which underpin how AM is conducted (ISO 55000), general requirements that should be applied when creating an AM system (ISO 55001), and guidelines for applying the requirements (55002). Combined they create the key concepts against which asset management activities are subjectively assessed during audit (Figure 38).

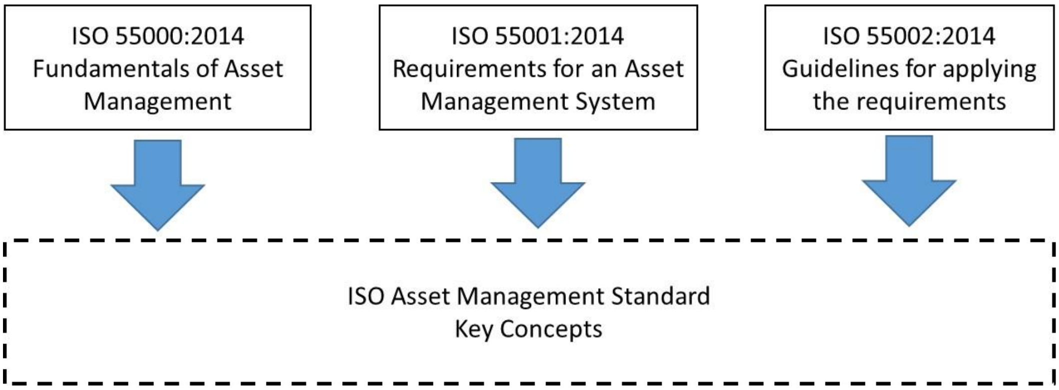


Figure 38. Identification of ISO 5500x:2014 Asset Management Standard key concepts

To identify these key concepts, thematic analysis of the suite of ISO documents (ISO 55000, 55001, and 55002) was undertaken. Qualitative analysis approaches are incredibly diverse, complex and nuanced (Holloway and Todres, 2003). Thematic analysis is a technique used to identify themes within qualitative data (Gray, 2014). It can be considered as a foundational method for qualitative analysis which is flexible, quick and easy to use, and accessible to researchers with little or no experience of qualitative research (Braun and Clarke, 2006).

Although, historically considered by some to be 'theory light', work by Braun and Clarke (2006) seeks to address these criticisms by providing practical guidelines for ensuring that the analysis is conducted in a determined and rigorous manner. The six phases of thematic analysis are presented within Table 22.

Table 22. Phases of thematic analysis (Braun and Clarke, 2006)

	Stages	Description
1	Familiarising yourself with the data	Reading and rereading the data and noting down initial ideas
2	Generating initial codes	Coding interesting features in a systematic fashion across the entire dataset, collating the data relevant to each code
3	Searching for themes	Collating codes into potential theme, gathering all data relevant to each potential theme.
4	Reviewing themes	Checking if the themes work in relation to the coded extracts and the entire dataset.
5	Defining and naming themes	Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells, generating clear definitions and names for each theme.
6	Producing the report	The final opportunity for analysis. Select vivid, compelling extract examples, final analysis of selected extracts, relating back of analysis to research question and literature, produce a scholarly report of the analysis.

In undertaking the thematic analysis NVivo software was used. NVivo is computer-based software that supports the analysis of qualitative data. One of the functions it offers, "code and retrieve", allows the user to code snippets of the data to different theme headings. These can then be retrieved and viewed separately – effectively organising the data so it is easier to access. Although it would have been quite possible to undertake a manual analysis, the use of software has been found to improve transparency (Hoover and Koerber, 2011). Furthermore, within this research it had the benefit of established a repository to which any qualitative data generated at later stages of the research could be added and analysed.

Analysis was undertaken across the suite of ISO 5500x documents. ISO 55000:2014 provides an overview of AM: the benefits, the approach taken, and the terminology. Within this document, the fundamental principles that underpin AM are defined (Table 23).

Table 23. Fundamentals of the Asset Management Standard (BS ISO 55000 Series: 2014)

Fundamental	Description
Value	Assets exist to provide value to the organisation and its stakeholders
Alignment	Asset Management translates the organizational objectives into technical and financial decisions, plans and activities

Leadership	Leadership and workplace culture are determinants of realization of value
Assurance	Asset Management gives assurance that assets will fulfil their required purpose

ISO 55001:2014, specifies generic requirements for establishment, implementation, maintenance and improvement of a management system for asset management. Finally, ISO 55002:2014 provides guidance on the application of a management system for asset management, in accordance with the requirements of ISO 55001:2014.

The purpose of the analysis was to identify key concepts (themes) which were relevant to the creation of a DST performance management approach. The coding to key concepts themes was inductive rather than to any pre-existing framework, with themes identified based on the researcher's interpretation of 'keyness' rather than number of appearances. This was further validated by NGET subject matter experts as part of the RE study (evaluation 2), by NGET subject matter experts during the industry evaluation presented in Chapter 9 (evaluation 4), and by a water sector subject matter expert during the transferability evaluation presented within Chapter 10 (evaluation 5).

This was considered preferential as some key concepts were specified within the fundamental principles, but make relatively infrequent appearances within the text i.e. life cycle approach.

The analysis followed the six step approach defined by Braun and Clarke (2006). This resulted in the identification of ten key concepts. Table 24 details the nine concepts and provides excerpts from the AM Standard that were coded to the theme.

Table 24. Key concepts within the ISO 5500x:2014 Asset Management Standard

Key Concept	Support
Process based	The AM system is a set of interrelated tools *"including policies, plans, business processes and information systems which are integrated to give assurance that the asset management activities will be delivered".* *The* processes are the elements which defined how activities are carried out. They are a set of *"interrelated or interacting activities which transforms inputs into outputs".* To manage assets in accordance with ISO 55000 *""The organization should develop processes to provide for the systematic measurement, monitoring, analysis and evaluation of the organization's assets".*
Process integration	Asset Management is not standalone. It will "*require collaboration among many parts of the organization".* *"A factor of successful asset management is the ability to integrate asset management processes, activities and data with those of other organizational functions, e.g. quality, accounting, safety, risk and human resources"*
Consultation and communication	*"Stakeholders generally need to be informed about the decisions that can affect them and might need to provide input into decisions that can have an impact on them"* *"Failure to both communicate and consult in an appropriate way about asset management activities can in itself constitute a risk, because it could later prevent an organization from fulfilling its objectives".*

Evolving	It is recognised that the environment in which AM takes place is not constant. *"The regulatory and legislative environment in which organizations operate is increasingly challenging and the inherent risks that many assets present are constantly evolving".* The organisation should not purely create and implement an AM system, it should be maintained and improved. *"the organization should outline how it will establish, implement, maintain and improve the system".*
Monitoring and continual Improvement	Continual improvement is defined as the *"recurring activity to enhance performance".* It is a *"concept that is applicable to the assets, the asset management activities and the asset management system, including those activities or processes which are outsourced".* The identification of *"Opportunities for improvement can be determined directly through monitoring the performance of the asset management system, and through monitoring asset performance".*
Life cycle approach	A fundamental principle of AM is that there should be *"processes for assurance of capability across all life cycle stages".* The stages of an assets life are undefined but *"can start with the conception of the need for the asset, through to its disposal, and includes the managing of any potential post disposal liabilities".*
Defined leadership	The success in establishing, operating, and improving AM is dependent on the *"leadership and commitment from all managerial levels"* To facilitate effective leadership there should be "clearly defined roles, responsibilities and authorities".
Contextual	Asset management is concerned with the realisation of value which contributes towards achievement of organisational objectives. What constitutes value is contextual it *"will depend on these objectives, the nature and purpose of the organization and the needs and expectations of its stakeholders".* The factors which influence the type of assets an organisation has, and how they are managed includes *"the nature and purpose of the organization; — its operating context".* When monitoring, measurement, analysis and evaluation the performance of assets the context of the organization shall determine: "a) what needs to be monitored and measured; b) the methods for monitoring, measurement, analysis and evaluation, as applicable, to ensure valid results; c) when the monitoring and measuring shall be performed; d) when the results from monitoring and measurement shall be analysed and evaluated".
Risk-Based	Risk defined within the Standard as the *"effect of uncertainty on objectives".* It is an expression of "consequences of an event", "and its associated "likelihood". The consequences can including impact on "*financial, health and safety, and environmental goals*". Within the Standard ""*risk" also includes opportunities".* "Asset management translates the organization's objectives into asset-related decisions, plans and activities, using a risk based approach" Rather than eradicate risk altogether is seeks to *"exploit opportunities and to reduce risks to an acceptable level".*

Step 2: Map stakeholder comments to key concepts

Within Step 2 the subject matter expert was asked to map terms and phrases within the stakeholder requirements to the Standard's key concepts.

As previously identified, the ISO AM Standard does not set specific requirements for managing the performance of DSTs. Rather, during assessments the auditor will determine whether they consider that the system, policies, and processes align to the key concepts within the Standard. The criteria they use in making this assessment are subjective. This has the potential to result in differing interpretation and criteria being applied.

Although there is no direct evidence of this in relation to the Asset Management Standard a study of auditors of the ISO 14001 Environmental Standard found that inconsistent interpretation of the key concepts did occur (Ammenberg *et al.*, 2001). Table 25 provides one example. During the study thirteen ISO 14001 auditors were asked the question "how do you control that the requirements regarding continual improvement is fulfilled?" The responses made showed there to be three different criteria which might be applied.

Table 25. ISO Auditors requirement for proof of continual improvement

Various Answers	Number of answers (percentage)
I focus on the environmental targets.	8 (62%)
I try to make a comprehensive judgement, where environmental targets constitute one part of.	4 (30%
I focus on procedures for handling non-conformance.	1 (8%)

There is evidence that this challenge of differing auditor interpretation of the Standards persists today. The Chartered Quality Institute, the professional body for those involved in the application and auditing of Standards, organised a recent event to discuss what adopting a 'process approach' really means. They state that although the term has been around for many years it hasn't necessarily been understood or implemented as intended (Chartered Quality Institute, 2018).

The rationale for asking the subject matter expert to undertake the mapping was therefore to capture their interpretation of where stakeholder requirements would be satisfied by the key concepts within the Standard. Furthermore, if there were stakeholder requirements that were not satisfied through the key concepts.

Table 26 presents a matrix which shows how the subject matter expert mapped the stakeholder requirements to the key concepts identified within the ISO AM Standard. On the pathway to industry adoption this mapping matrix provides a basis for identifying whether there are inconsistencies of interpretation across stakeholders, and if requirements and interpretations evolve.

Table 26. ISO 5500x:2014 Key Concepts mapped to NGET identified stakeholder requirements

	Process Based	Process Integration	Communication & Consultation	Evolving	Monitoring and Continual Improvement	Life Cycle Approach	Defined Leadership	Contextual	Risk Based
Life-cycle value achieving customer requirements and over delivery of regulatory performance	✓	✓		✓	✓	✓		✓	
Industry compliant conforms to ISO 55000 and ISO 31000	✓			✓					
Adaptable to asset base, satisfies data requirements and organisation systems	✓			✓	✓				
Performance to be agile. Accurate tool that produces validated results					✓			✓	
Technical competence reflecting asset position and network risk		✓		✓		✓		✓	✓
Life-cycle management, safe, credible, economic and efficient.	✓	✓		✓		✓		✓	✓
Value, safe environmentally. Adhering to International Standard	✓			✓				✓	
Delivers credible results						✓	✓	✓	
Agile can be upgraded				✓	✓				
We know how it works	✓	✓		✓					
Safe, reliable, and efficient outputs which are understood	✓		✓			✓		✓	
Consistent with consumer value mechanistic approach easy to understand translating inputs, process, outputs.	✓	✓							
Transparent, consistent with Scots TO's			✓						
Stable – repeatable and reproducible	✓								

Although there was no direct mapping, the NGET subject matter expert was able to map all of the stakeholder requirements to the ISO standard key concepts. Indeed, they did not voice that they had any difficulty in completing the task. This is perhaps a consequence of the expertise of the subject matter expert. Whether this would be the case if the participant was less familiar with the ISO AM Standard is uncertain.

For twelve of the fourteen, the requirement was not satisfied through mapping to one, but multiple key concepts. For example, the requirement of "Life-cycle value achieving customer requirements and over delivery of regulatory performance" was mapped to six key concepts: process based, process integration, communication and consultation, evolving, monitoring and continual improvement, life cycle approach, and contextual.

Receiving the most support was that the approach should be process based (9), evolving (8), and contextual (7).

When undertaking the thematic analysis of the ISO AM Standard it had (perhaps understandably) not captured that the DST performance approach should be ISO

Standard compliant. This was considered by the subject matter expert to be an important requirement that warranted inclusion.

Within the stakeholder requirements was a statement that the approach be "consistent with Scots TO's", and "over delivery on regulatory performance". Currently, there is no industry or regulatory requirement for DST performance to be managed. Although the Scottish Transmission operator (Scottish Power) may well have undertaken activities aimed at managing the performance of their DSTs, these are not established 'good' practice, or published in the public domain. Consequently, when designing an approach it would not currently be a case of aligning with what is done within Scottish Power, but in designing an approach that would be transferable to them.

Receiving the least support was that there should be defined leadership. Although not receiving strong support it was mapped to the requirement for "delivers credible results". Within the Standard, there is a specific requirement that there should be "clearly defined roles, responsibilities and authorities"; indeed defined leadership is a principle that underpins the design of a Quality System (ISO 9001). Whether the lack of obvious support for defined leadership was down to a simple omission, or a lack of explicit understanding of the requirements of an ISO quality managed system, was unclear.

6.3.3 Documentation Results

Based on the results of the analysis ten approach requirements were defined:

R1	ISO Standard compliant
R2	Process based
R3	Process integration
R4	Consultation and communication
R5	Evolving
R6	Monitoring and continual Improvement
R7	Life cycle approach
R8	Defined leadership
R9	Contextual
R10	Risk-Based

6.3.4 Validation Results

Table 27 presents the results of the validation questionnaire completed by the two subject matter experts as part of the focus group.

Table 27. Requirements validation questionnaire responses

		Respondent 1	Respondent 2
	Job Title	Information Quality Officer	Analytics Development Leader
1A	Are there any stakeholders identified who you feel should not be included? If so, provide detail and reasoning.	No	No
1B	Are there any approach stakeholders who you feel have not been identified? If so, provide detail and reasoning.	Suppliers i.e. IBM, Wipro who provide services to build the DST (SAM) platform	Possibly suppliers as they would have their own input to the process.
2A	Are there any stakeholder requirements you feel should not be included? If so provide the detail and reasoning.	No	No
2B	Are there any stakeholder requirements which you feel have not been identified? If so provide the detail and reasoning.	No	No
3A	Within the stakeholder requirements it was identified that the approach should conform to ISO 55000 and ISO 31000. Do you agree with that statement? YES / NO If 'No' provide your reasoning.	Yes	Yes
4A	Are there any approach requirements you feel should not be included. If so, provide the detail and justification.	No	No
4B	Are there any approach requirements which you feel have not identified? If so, provide the detail and justification.	No	No

The responses show there to be complete consensus between the two participants. Whether this was achieved as a consequence of the discussions which took place during the focus group is unknown. That a consensus was found is significant as both stakeholders will be operationally involved with the DST performance management approach. If their responses had differed further analysis and negotiation would have been necessary.

The respondents both confirmed that there were no stakeholders identified who they thought should not be included (1A). However, both suggested that *suppliers*, who had not previously been identified as a stakeholder, should be included (1B). Within NGET, consultancies are used to create and manage some of their DST. An example of this is the Strategic Asset Management (SAM) DST (Chapter 5, 5.4.3). Consequently, if SAM were to be included within the scope of DSTs that are performance managed, suppliers would become a stakeholder.

Although suppliers were identified as an additional stakeholder, the respondents did not suggest that they had additional requirements above those that had previously been generated by the NGET subject matter expert during brainstorming (2B). Additionally, there were no stakeholder requirements that they felt should not be included (2A).

The literature review and the NGET both concluded that when designing the approach it was vital that it align to the requirements of the ISO AM Standard. The input from the NGET subject matter expert supported this belief. The responses of the participants further support this view with both participants agreeing that the approach should conform to ISO 55000 (Asset Management) and ISO 31000 (Risk Management).

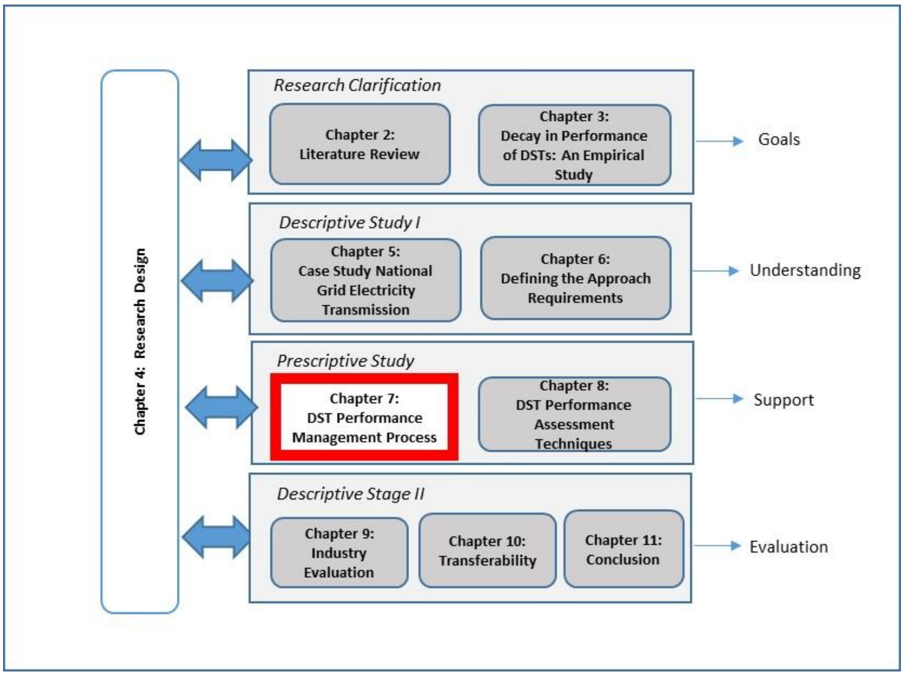
The process undertaken in order to arrive at the documented approach requirements was not straightforward. Although a transparent and systematic process had been followed, there was still the potential for misinterpretation and researcher biases to affect the approach requirements that were documented. There is also the possibility that although translated accurately, these requirements do not match with what the two experts consider necessary. Both participants confirmed that the ten approach requirements were valid – there were no requirements missing (3B), nor any which should not have been included (3A).

6.4 Chapter 6 – Summary Points

- The ISO 5500x:2014 Asset Management Standard is a constraint on how an approach for managing DST performance is designed.
- There are no specific requirements for design of a DST performance management approach within the ISO AM Standard.
- There are key concepts within the AM Standard with which AM activities should align.
- Key concepts within the ISO AM Standard are subjective.
- Stakeholder requirements do not map directly to key concepts within the ISO AM Standard.
- The RE exercise, conducted with NGET subject matter experts, resulted in the defining of ten requirements for the conceptual design (R1-R10).

The research conducted within Chapters 5 and 6 provided the context of DST use with NGET, and defined the requirements of an approach for managing DST performance within this context. Within the following chapters, that understanding was used to inform the design of an approach to manage DST performance.

Chapter 7: DST Performance Management Process



Within the Prescriptive Study stage, understanding gained from conducting the research was used to inform the creation of a DST Performance Management Process and DST Performance Assessment Techniques.

Within Chapter 7, the novel DST Performance Management Process created within this research is presented. This represents a risk-based, continually improving process for managing the performance of DSTs used within an AM context. The Chapter is structured as follows: First, the context of the DST performance management approach (7.1). Following, the DST Performance Management Process is presented in detail (7.2). An analysis of how the process addresses the ten approach requirements defined within Chapter 6 is provided (7.3). The process is verified and validated by NGET subject matter experts (7.4). Finally, summary points highlighting the key findings are provided (7.5).

7.1 Context of the DST Performance Management Approach

Key to understanding the DST Management approach that has been created is an appreciation of the context in which it will operate. The approach does not work in isolation. It is contained within a hierarchy that translates the ISO 5500x:2014 AM Standard into the processes and techniques that define how AM is conducted within an organisation. Figure 39 places the DST Performance Management Process and DST Performance Management Techniques within the AM hierarchy.

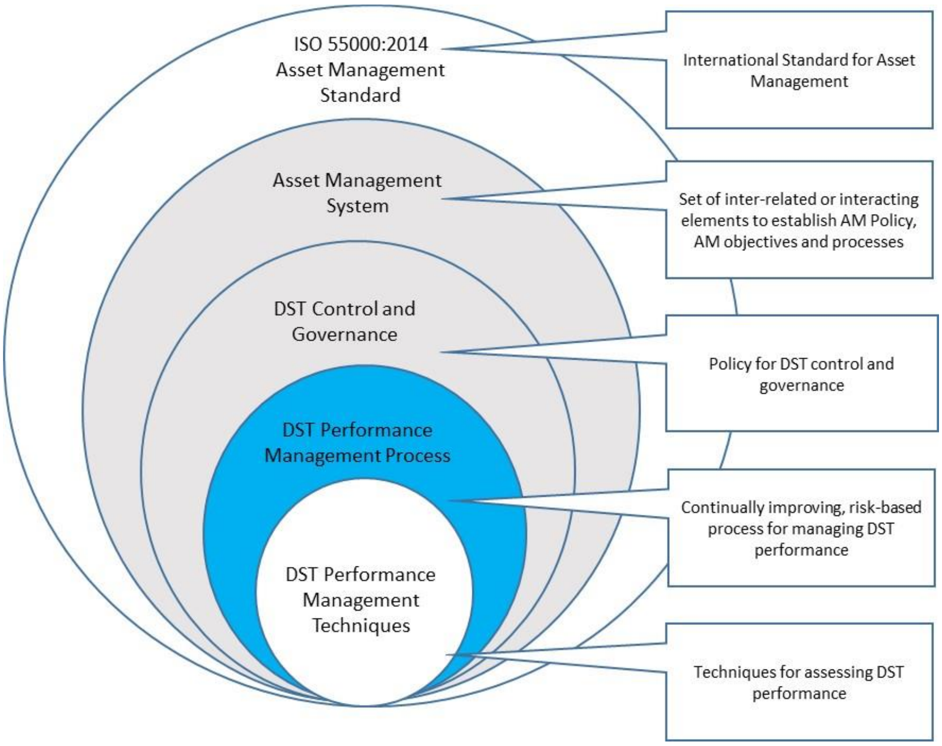


Figure 39. The DST Performance Management Process within Asset Management hierarchy

Embedding the process within the AM system was considered advantageous for two main reasons.

- First, by recognising the process within an organisational management system it becomes subject to quality management activities including document control and audit. This increases transparency and ensures that the process is regularly monitored and reviewed.
- Second, the AM system provided an appropriate management system for the process to be seated. DSTs have varying types. Whereas some AM DSTs are customised computerised systems, they also encompass computer based database / spreadsheet reports and manual processes. The different types of DSTs mean that placing the process within for example, an organisation's Software Asset Management System (BSI ISO/IEC 19770-1: 2012), would mean that only some of the tools would be within scope. By embedding the process within the AM System, all DSTs can be included. Ensuring visibility of all DSTs is essential for a risk-based performance management approach. That is, in order to make informed decisions on which DSTs to focus performance management

actions, and what action to take, it is necessary have a full understanding of the DSTs which are being used.

At the top level is the international Standard for Asset Management ISO 5500x:2014. As identified within the literature review (Chapter 2, 2.1.3), the NGET case study (Chapter 5, 5.1), and in defining the approach requirements (Chapter 6, 6.3.1), within the UK infrastructure sector aligning your AM practice to AM Standards is desirable and encouraged by UK industry regulators.

ISO 5500x:2014 defines the requirements for an Asset Management system. An AM system comprises of the organisation's policies and procedures for applying AM in practice (BS ISO 55000 Series: 2014).

Forming part of the AM system should be the policy for DST control and governance. This defines how DSTs will be managed at the different stages in their life. That is, the DST Performance Management Process manages performance during the operational stage of a DST. Wider control and governance will be required to cover the full life cycle of the DST i.e. creation, implementation, and disposal.

The DST Performance Management Process is the means through which to manage DST operational performance. It contains the steps to undertake a DST Performance Assessment, and elements which ensure that the process meets the requirements for a quality managed process as defined within ISO 9001:2014 Quality Management Systems (BS EN ISO 9001: 2015).

The DST Performance Management Process details the process for DST performance management. It does not provide the 'how to' techniques for applying the process. These are defined within the DST Performance Management Techniques (Chapter 8).

7.2 The DST Performance Management Process

The novel DST Performance Management Process created within this research reflects the same overarching design as the Risk Management Process defined within ISO 31000:2009 Risk Management standard (BS ISO 31000: 2009). This was considered advantageous for three reasons:

- First, the International Organisation for Standardization aims to achieve standardisation of terminologies. This ambition is evidenced through the creation of a Standard which establishes the basic principles and methods for compiling terminologies both inside and outside of the framework of standardization (BS ISO

704: 2009). Basing the process on the ISO Risk Management Process ensured commonality of terms.

- Second, the Risk Management Process is presented as an exemplar by the International Organization for Standardization. That is, it has been accepted within the organisation as demonstrating 'good' process design.
- Third, the literature review identified that AM aims to achieve the optimum value by the balancing of asset performance, cost, opportunity, and risk (Chapter 2, 2.1.3). In managing risk, the Asset Management Standard references the Risk Management Standard (BS ISO 31000: 2009). That is, for guidance on managing AM risk the Standard directs the reader to the ISO 31000 Risk Management Standard. Basing the process on the ISO Risk Management Process meant there was commonality of design across the two standards.

The novelty in the DST Performance Management Process is that the Risk Assessment is replaced by the DST Performance Management Assessment. Additionally, whereas the Risk Management Process is visualised as isolated from other processes, the DST Performance Management Process integrates within other management systems and/or governance processes when applying a treatment (Figure 40).

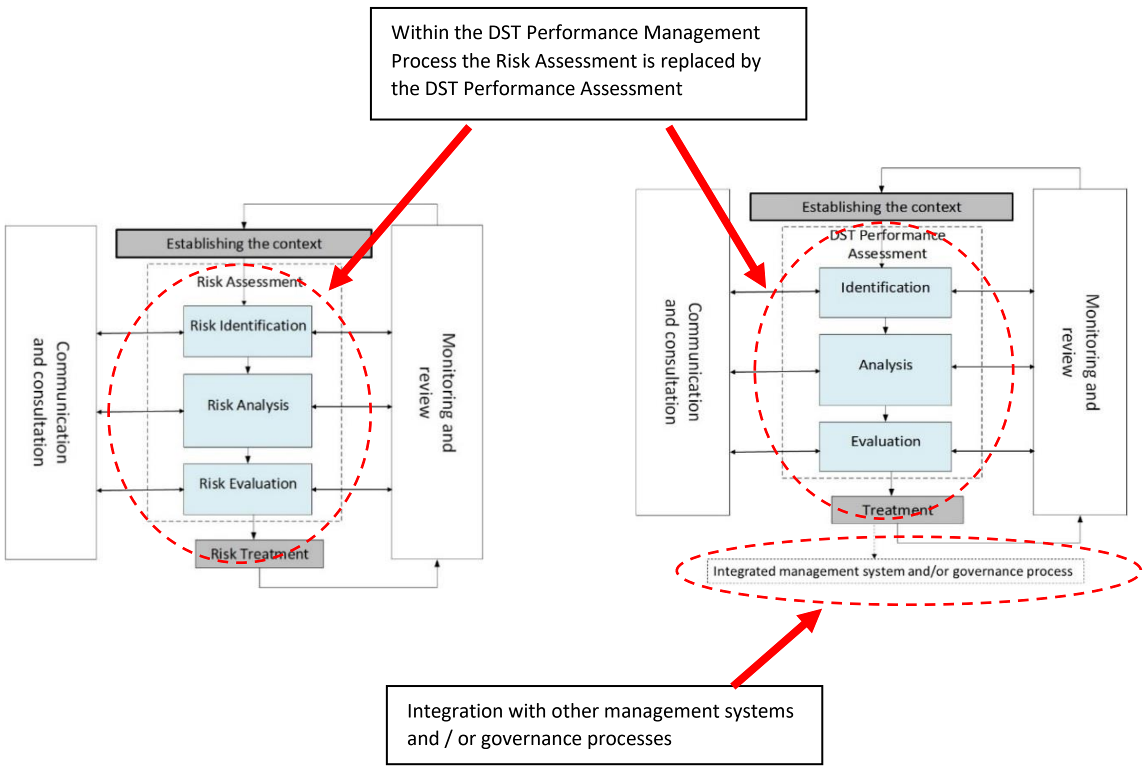


Figure 40. Comparison DST Performance Management to ISO Risk Management Process

Figure 41 presents DST Performance Management Process in detail. This shows that the elements common to both processes are: *Communication and consultation, Monitoring and review, and Establishing the context.* The DST Performance Assessment is the area within the process where you 'DO' DST performance management. Mirroring the Risk Management Process, it contains three elements: *Identification, Analysis, and Evaluation.* Although containing the same three elements the activity conducted under each is novel.

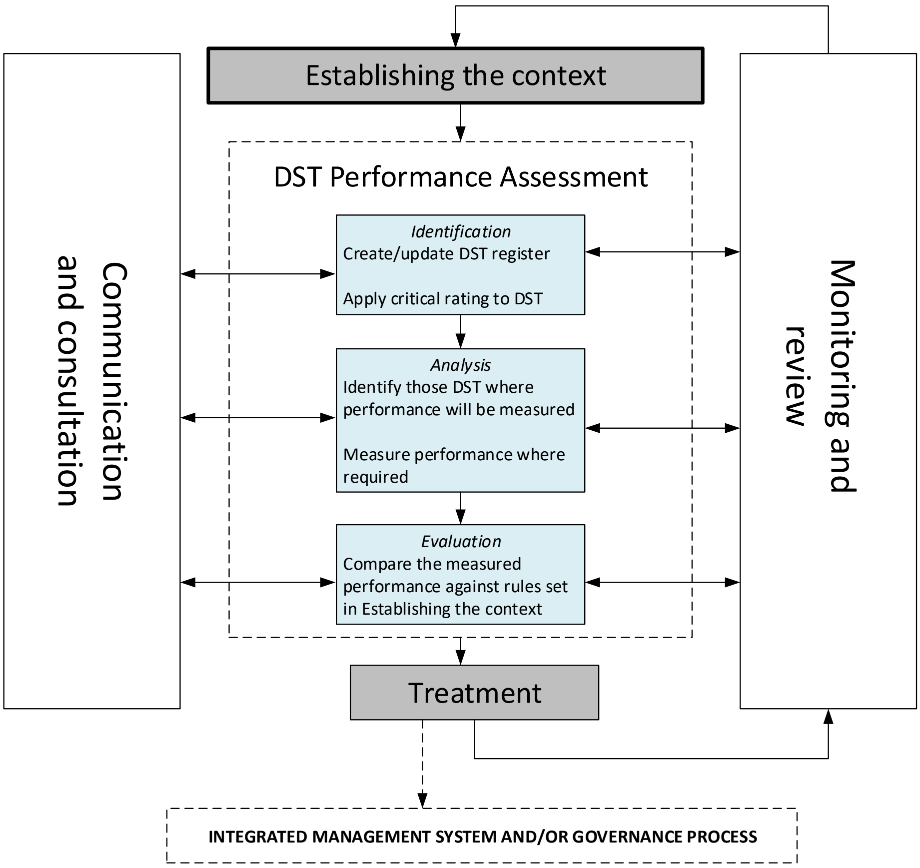


Figure 41. The novel DST Performance Management Process

Communication and consultation* and *Monitoring and review create a continually improving process cycle. *Consultation and communication* ensures that differing stakeholder views are considered and that they are informed so that they understand the basis on which decisions are made and the reasons why particular actions were required. *Monitoring and review* takes actions to provide assurance of the effectiveness and efficiency of the process.

Establishing the context is the means through which a generic process is adapted to the organisational context. Within the Risk Management Process, it defines the objectives, internal and external context, and sets the risk criteria for the remaining process. The DST Performance Management Process adopts the same approach. It defines the internal, external, and process context, and the rules for applying the rest of the process. That is, the rules that an organisation will follow when applying the steps contained within the DST Performance Assessment.

The basic requirements under each of the areas are defined in Table 28. The external, internal and process context have been slightly adapted to fit the environment, but generally reflect that seen within the ISO 31000:2009 Risk Management Process (5.3.2 – 5.3.4). The *rules* context area is unique and has been created within this research. Within this area the requirements have been defined to align to the specific steps of the DST Performance Assessment.

Table 28. Basic Requirements under Establishing the context

Area	Basic Requirements
External	• Social and cultural, political, legal, regulatory, financial, technological, economic, natural and competitive environment, whether international, national, regional or local; • Key drivers and trends having impact on the objectives of the organization; • Relationships with, perceptions and values of external stakeholders;
Internal	• governance, organisational structure, roles and accountabilities; • policies, objectives, and the strategies that are in place to achieve them; • capabilities, understood in terms of resources and knowledge (e.g. capital, time, people, processes, systems and technologies); • the relationships with and perceptions and values of internal stakeholders; • the organisational culture; • information systems, information flows, and decision making processes (both formal and informal); • Standard, guidelines and models adopted by the organisation; • Form and extent of contractual relationships;
Process	• The goals and objectives of the DST Performance Management Process; • Defining responsibilities within the DST Performance Management process; • Defining the scope of the DSTs which will be included under the process; • Defining the process in terms of time and location; • Defining the relationships between the process and other processes; • Defining the process techniques; • Defining the way in which performance and effectiveness of the process will be monitored and reviewed; • Defining the communication and consultation strategy;
Rules	• The rules used to establish how critical the DST is; • The rules which determine which DSTs shall have their performance measured; • The rules against which the DST performance measure is evaluated. • The rules which determine the treatment that is applied to a given performance evaluation outcome.

The *internal* and *external* context identify the environment in which the organisation seeks to achieve its objectives. This can include but is not limited to the regulatory, economic, and political factors that create the external environment, and the business objectives, organisational structure, and culture that create the internal environment. Although these areas would have been considered when establishing the AM System, within *Establishing the context* these areas are specifically considered in relation to the process. The *process* context sets the objectives, strategies, scope and parameters. This includes not only the goals and objectives of the process but authority and responsibilities, and methods that assure process performance. Within the *rules* there are four requirements. These relate directly to the specific steps conducted within, and in the action that is taken as a result of undertaking the DST Performance Assessment.

Within the DST Performance Assessment there are three steps: identification, analysis, and evaluation:

Identification is the process of capturing data about the DSTs used within the organisation. It provides a comprehensive list of all DSTs that fall within the scope (as defined by the organisation within E*stablishing the context)*, their criticality to the business, and data relating to their performance management. Performance management data is generated through application of the DST Performance Management Process.

Analysis is the stage during which the DSTs that require their performance to be measured are identified. Analysis uses the rules defined within E*stablishing the context*. Where appropriate the performance of an individual DST will be measured.

Evaluation takes the results obtained when measuring performance and applies the rules defined within *the Establishing the context* element, to determine whether the performance is acceptable or not.

Treatment is the action in response to conducting the assessment. It is decided according to the rules defined within *Establishing the context*. Treatments will be determined by the organisation and will take account of a number of factors including: costs versus benefit, legal /statutory requirements, and social responsibility etc. Treatment can either be contained within the process i.e. create a report for senior management, or update the rules contained within E*stablishing the context*. Alternatively, it might transfer the treatment action to a separate, but integrated process. For example, as a result of the performance assessment it could be decided that a risk assessment was required. In this case the treatment (the risk assessment), might be undertaken as part of an organisation's Risk Management system. Any treatment taken would be evaluated as part of the *Monitoring and review* activity and in doing so, close the quality improvement loop.

7.3 DST Performance Management Process - Analysis against Requirements (R1-R10)

Chapter 6 defined ten requirements (R1-R10) for a DST performance management approach. This section analyses how the DST Performance Management Process addresses each of these ten requirements. It brings together knowledge and understanding gained during the literature review, the NGET case study, and in the process of defining the approach requirements. A summary of the discussion is presented within Table 29.

Table 29. Summary. Analysis against requirements

Unique Identifier No.	Requirements	Summary
R1	ISO Standard Compliant	The DST Performance Management process has been designed to reflect key concepts seen within the ISO 5500x:2014 Asset Management Standard. These concepts are subjective. Evidence shows that they are interpreted differently by ISO practitioners. It is expected that interpretations will evolve over time. An evolutionary design is required to incorporate emerging and evolving perspectives.
R2	Process based	Defined, systematic approach. Aligns to the exemplar Risk Management Process, published within ISO 31000:2009 Risk Management standard.
R3	Process integration	Process design to be in harmony with ISO 31000:2009. Integration of the approach specifically seen at the treatment level.
R4	Consultation and communication	Two way interaction between stakeholders and the process achieved through the *Communication and consultation* element. Communication activities are tailored to meet the needs of the organisation by way of the *Establishing the context* element.
R5 R6	Evolving Monitoring and continual improvement	The DST Performance Management Process sits within the AM system. The requirements of the Standard ensure continual improvement at a system level. The DST Performance Management Process is cyclical and incorporates a Monitoring and Review element. Feedback loops ensure evolution and continual improvement at a process level.
R7	Life cycle approach	Provides a solution through which to manage the operational performance of DSTs. It does not extend to cover all life cycle stages i.e. from the identification of a need, to disposal.
R8	Defined leadership	Governance, organisational structure, roles and accountabilities are defined within the *Establishing the context* element.
R9	Contextual	Tailors the process to the context of the organisation through the *Establishing the context* element
R10	Risk-based	*Establishing the context* element allows the scope of the DSTs included, and the performance management activities undertaken to reflect the risk tolerance of the organisation

7.3.1 ISO Standard Compliant (R1)

The literature review identified that the scope of assets managed within an AM system is determined by the organisation (Chapter 2, 2.1.3). Therefore, there is no requirement for an organisation to have a documented process to manage DST performance. The case study identified that NGET undertake various activities to control and govern the performance of their DSTs. However, these activities are not controlled by co-ordinated processes that form part of their AM system. Despite this, their AM system is certified under ISO 55001:2014.

However, what would be the situation if DST were included within the scope of an organisation's AM system? As identified, ISO 55001:2014 Asset Management Standard does not set specific requirements for managing the performance of a DST. However, for any process to be acceptable, an auditor must be satisfied that any approach aligns with the key concepts found within the Standard (Chapter 6, 6.3.2).

When defining the ten approach requirements the ISO AM Standard key concepts were identified. The stakeholder requirements were mapped to them as a way of identifying any conflict or omissions. Through this approach, the key concepts of the Standard were central to the design of the DST performance management approach. Although mitigating the risk that the approach does not align, ultimately the judgements made by auditors on whether an approach is acceptable will be subjective and will reflect the reality of an individual at a point in time (Chapter 6, 6.3.2).

The use of the evolutionary research approach (Chapter 4, 4.2), accepts that requirements will emerge and realities will evolve. The creation of the stakeholder requirements matrix (Chapter 6, Table 26) provides a mechanism for identifying stakeholder requirement inconsistency and change.

7.3.2 Process Based (R2)

When defining the approach requirements it was identified that even within the Chartered Quality Institute, the professional body for those involved in the application and auditing of Standards, there is continuing debate about what adopting a 'process approach' means (Chapter 6, 6.3.2).

Standards do not operate in isolation. They are written to work in harmony with the other Standards and in doing so encourage a coordinated system of 'good' working practice. Within the ISO AM Standard, a process is described as the "interrelated or interacting activities which transforms inputs into outputs". However, the ISO Standard for Quality

Management Systems (BS EN ISO 9000: 2015) – the requirements of which underpin the AM Standard - defines that a quality managed process should be designed in accordance with the Deming PDCA (Plan-Do-Check-Act) cycle. Figure 42 shows the alignment of an ISO quality managed process with the Deming cycle. This shows that when designing a process it should include elements through which to understand the organisational context and the needs and expectations of stakeholders, and have a cyclical design that incorporates performance evaluation and improvement.

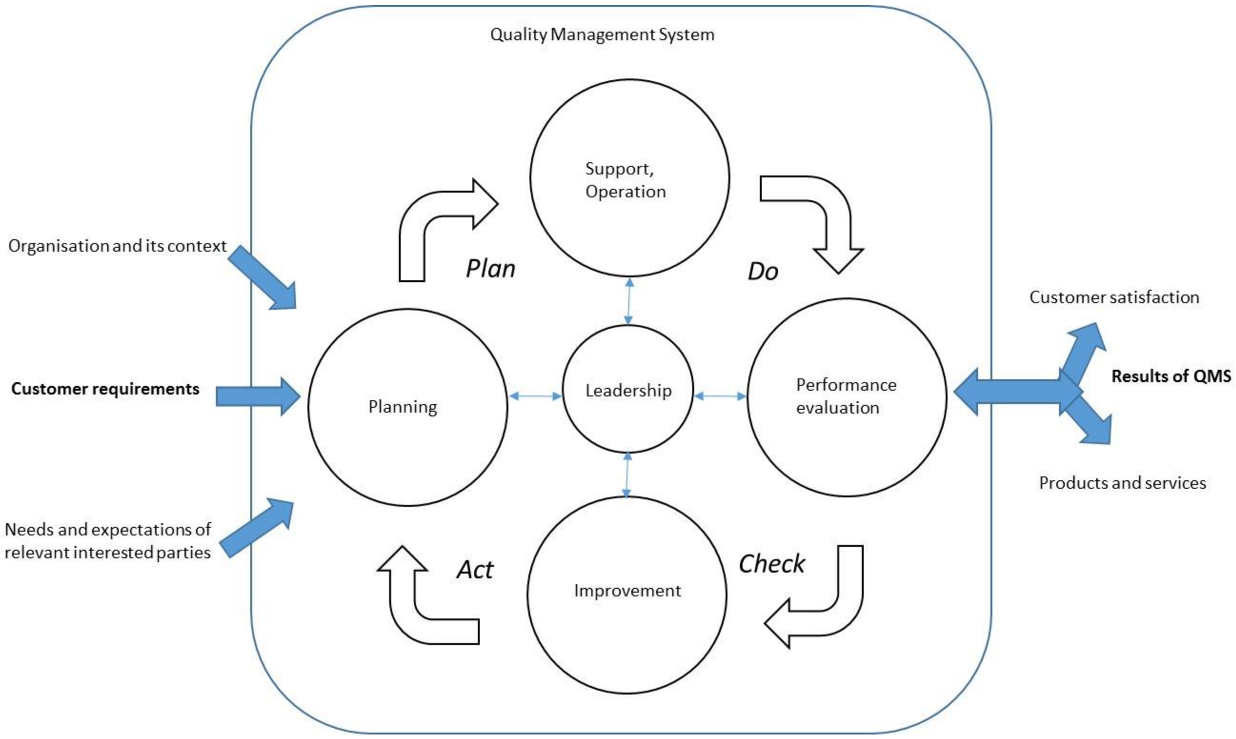


Figure 42. Structure of the ISO 9001: 2014 Standard in the PDCA cycle (BS EN ISO 9001: 2015)

The Risk Management Process is presented as an exemplar process by the International Organization of Standardization. It contains the elements and meets the design of a quality-managed process. Therefore, basing the DST Performance Management Process on the Risk Management Process ensured that it too meets the requirements of an ISO quality managed process.

7.3.3 Process Integration (R3)

Asset Management does not happen in isolation. It is cross-functional, requiring collaboration among many parts of the organisation. Although giving an indication of areas where integration might be possible, it does not state specific processes where integration should be seen, or provide an indication of what integration might look like, or how it might be achieved.

Likewise, the stakeholders requirements captured during elicitation (Chapter 6, 6.3.1) are not specific regarding with which organisational systems the DST Performance Management Process should integrate.

As stated previously, for guidance on managing AM risk the Standard directs the reader to the ISO 31000 Risk Management Standard. Basing the DST Performance Management Process on the Risk Management Process ensures integration across these two Standards.

However, the Risk Management Process is in itself not integrated. It is visualised as a self-contained process (Figure 40). The DST Performance Management Process illustrates integration at the treatment stage. That is, when applying a treatment the action can be transferred to a separate management system and/or process. For example, one of the defined treatment actions might be to conduct a risk assessment. The risk assessment might be undertaken by way of the Risk Management Process, and managed from within the Risk Management System.

7.3.4 Communication and Consultation (R4)

Poor communication and the lack of a common vision have been identified as barriers to the sustainment of business improvement initiatives (Hicks and Matthews, 2010; Sarker *et al.*, 2006; Studer, 2014). Thematic analysis of the ISO AM Standard (Table 24) identified that communication should be two-way with stakeholders being both informed and able to input. In keeping with the nonprescriptive approach the Standard does not set specific requirements for what, when, and how to engage with stakeholders.

Within the DST Performance Management Process communication and consultation is an element of the process. Two-way directional arrows show that this activity both takes inputs from, and provides outputs to, the stakeholders. The communication strategy is determined by the organisation and defined by them within *Establishing the context*. In this way consultation and communication reflects the context of the organisation.

7.3.5 Evolving (R5) and Monitoring and Continual Improvement (R6)

Continual improvement is a continuous act, which looks to eliminate waste and identify areas for improvement (Sanchez and Blanco, 2014). It is considered a vital element of achieving business excellence and is a concept which permeates throughout the International Standards as well as management systems such as Lean Management

(Womack, 1990), and TQM (Bajaj *et al.*, 2018). Within the ISO AM Standard it is defined as the "reoccurring activity to enhance performance". The concept of continual improvement applies not only to the management of the assets, but also to the management system including any processes within it (BS ISO 55000 Series: 2014).

In conducting the thematic analysis of the AM Standard continual improvement was considered to be a different concept to evolving. The interpretation was that whereas monitoring and continual improvement look to improve the system, *evolving* might be considered to be maintenance. An evolving process may result in increased performance; equally, it may be used to prevent a reduction in performance. The case study identified that over the period 2011 to 2016 there was a change in the organisational objectives of NGET (Chapter 5, 5.1.1). Therefore, to prevent a reduction in the performance of the process, the rules (e.g. criteria used to identify critical DSTs) may need to evolve.

The DST Performance Management Process is based on the ISO 31000:2009 Risk Management Process (BS ISO 31000: 2009). Figure 43 shows how the principles underpinning the ISO Risk Management standard set a requirement for a continually improving framework (system) for managing risk. The operational aspect of risk management – the steps to follow when managing risk - are defined within Risk Management Process. The key activities of the risk assessment (identification, analysis, evaluation), sit within a broader process that includes *Establishing the context*, *Communication and consultation, Monitoring and review*. In combination, they create a continually improving process for managing risk.

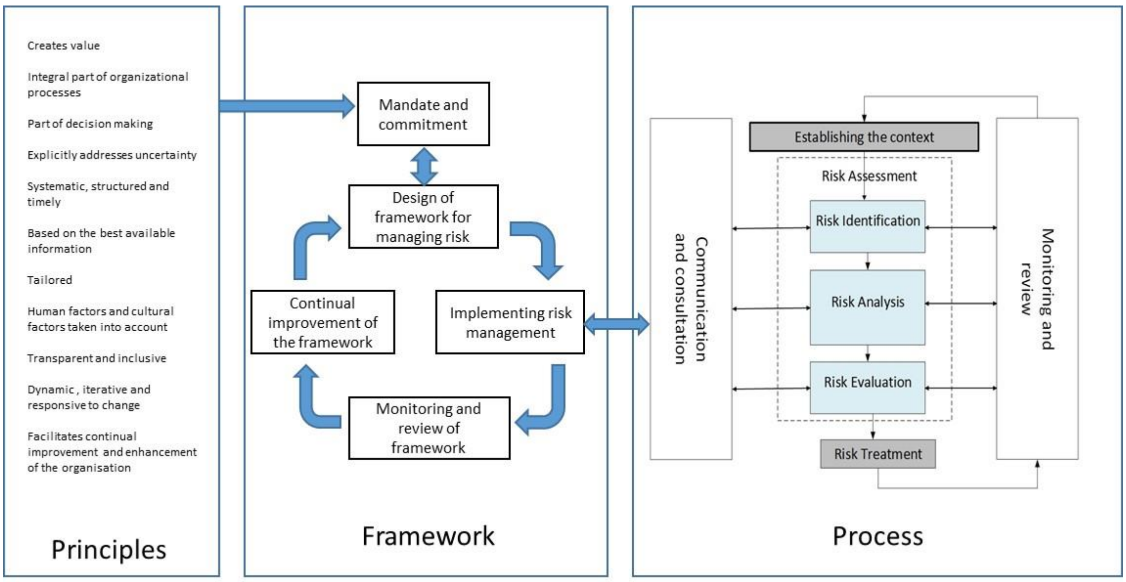


Figure 43. Relationship between risk management Principles, Framework, and Process

The Asset Management Standard follows the same overarching design. The Asset Management Standard is based on a set of fundamentals (principles); these are translated into a continually improving system (framework) through which to manage assets. The Asset Management System. Forming part of this system are the processes that determine how the asset management activities are conducted. In this regard within the Asset Management System, the DST Performance Management Process assumes the same place in the hierarchy as the Risk Management Process (Figure 44). The cyclical process that includes *Monitoring and review*, provides a mechanism through which to not only continually improve but also evolve (maintain) the system.

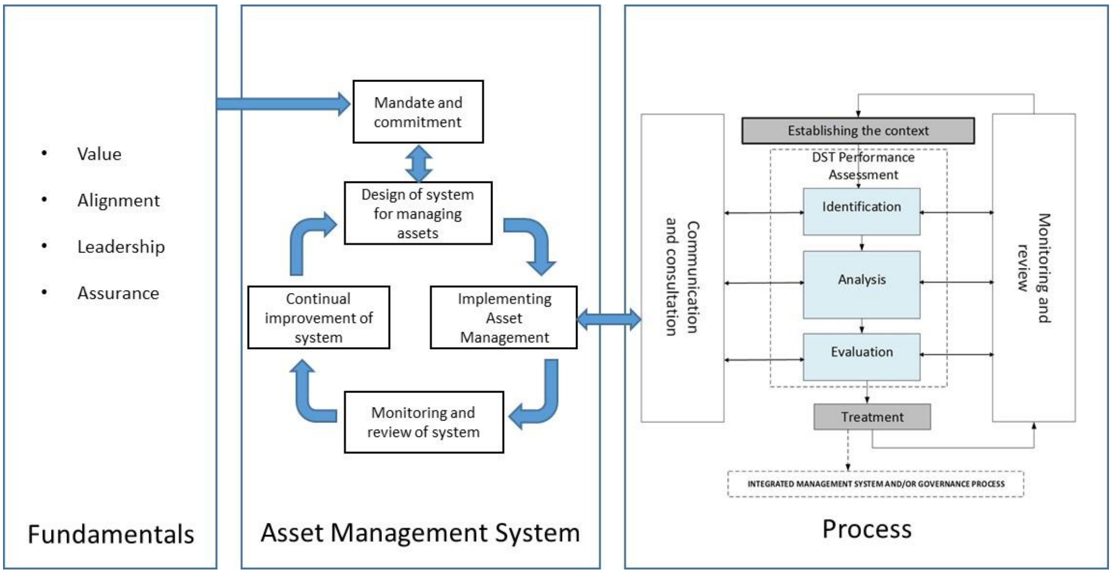


Figure 44. AM fundamentals, System, and DST Performance Management Process

7.3.6 Life Cycle Approach (R7)

The ISO AM Standard advocates a life cycle approach be taken to assets. That is, there should be assurances of capability across all life cycle stages (BS ISO 55000 Series: 2014).

The Asset Management Standard does not define what the life cycle stages are. Rather that the naming and numbering of stages will vary depending on the industry sector (BS ISO 55000 Series: 2014). Figure 45 provides three examples of asset life cycle stages taken from an Institute of Asset Management (IAM) publication.

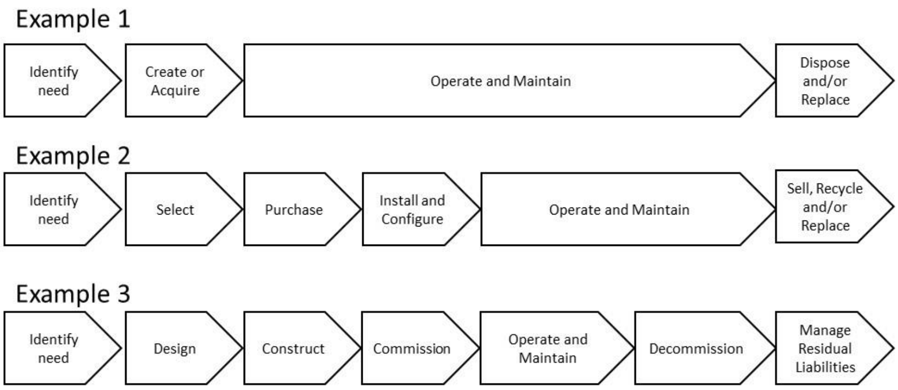


Figure 45. Variations in asset life cycle stages (IAM, 2016d)

The NGET case study presents three example DSTs (Chapter 5, 5.3). These demonstrate differing life cycle stages. Both the Whole Life Value Framework (WLVF) and the Network Output Measures (NOMs) tools align most closely with the stages shown in the example 1, Figure 45. Although the most closely mapped, they are not completely aligned as there is no recognition of a pilot stage which took place for both DSTs. On the other hand, the Strategic Asset Management (SAM) tool was not created but purchased, and then configured and installed. In this regard it aligns most with example 2.

Accepting that there are differences, the commonality in the three examples shown within Figure 45 is that they begin at identification of a need and end at disposal. The DST Performance Management Process does not manage performance across the entirety of this period. It creates a systematic, approach for measuring, monitoring, analysing, and evaluating the performance of DSTs during their operational life. As shown in Figure 39, it is intended that the DST Performance Management Process should form part of a wider arrangement for DST control and governance. To cover the whole life cycle of a DST control and governance should include processes for DST creation, implementation, and disposal.

7.3.7 Defined Leadership (R8)

The literature shows that management commitment is essential to the successful implementation of a project (Dennis *et al.*, 2003; Redman and Grieves, 1999; Sarker *et al.*, 2006). Indeed, it is shown as central to the design of a quality-managed system (Figure 42).

The NGET case study shows that their DSTs are used across functions and encompass a range of types that includes manual and computer based DSTs (Chapter 5, 5.3). This would mean that they would naturally not fall under the responsibility of any one area. For example, the WLVF was created, maintained, and used within the asset management area. On the other hand, the SAM DST was created and maintained by a supplier, but used within the asset management area. To ensure a coordinated approach the governance, organisational structure, roles and accountabilities under the process are defined within the *Establishing the context* element.

7.3.8 Contextual (R9)

Organisations are not the same. This is recognised within the Asset Management Standard whereby the scope of an organisation's Asset Management system, and the policies and the processes it adopts, are determined by the organisation and are dependent on both their external and internal context (BS ISO 55000 Series: 2014).

The DST Performance Management Process has been designed to be generic. *Establishing the context* tailors the process to the specifics of the organisation. This customisation extends to the scope of the DSTs which will be included, the rules used to rate how critical they are, the rules which determine which DST shall have their performance measured, the rules used in evaluating the performance, and the treatment which is applied to a given performance evaluation.

When considered within the context of the NGET case study, three main benefits are seen. First, the process will reflect the specific context of NGET. That is, the internal and external factors that will determine how they operate and what they consider to have value can be incorporated. Second, the process is not static. As the environment in which NGET operates changes, or organisational thinking evolves, the process can be adapted. For example, when the organisational objectives change, the rules used to apply a critical rating can be updated. Third, it allows NGET to adapt the scope and scale of the management to reflect the resources they have available. For example: (1) the case study identified that NGET have in excess of 200 DSTs. At first introduction, the scope of the system could be restricted to specific types of DSTs. Once implemented, the scope could be increased. (2) on first introduction the treatments applied might be restricted to actions that are quick and easy to carry out. Once implemented, the rules can be changed to incorporate treatments that are more involved. If NGET then found that they had insufficient resource to deal with the more time consuming treatment actions, the rules could be scaled back returning treatments to the previous level. That is, the process can be tailored to the resources available at a specific point in time.

7.3.9 Risk Based (R10)

The ISO AM Standard states that a risk-based approach is used in asset related decision-making (Table 31). However, it does not define what 'risk-based' might mean in practice.

The Asset Management Standard integrates with the ISO 31000:2009 Risk Management Standard (BS ISO 31000: 2009). That is, for more detail on risk the reader is referred to Risk Management Standard. Within this Standard 'risk' is defined as the "effect of uncertainty on objects" which is often characterised by the probability and consequences of a risk event occurring. In this regard taking a 'risk-based approach' might be interpreted as not applying a blanket action, but rather that the actions associated with assets are taken based on an assessment of the possibility and consequences of a risk event occurring. For example, when deciding which pylons to paint NGET would look at all pylons and base their decision on which had the greatest possibility of corrosion, and what the consequence of any corrosion might be.

The NGET case study shows the importance of taking a risk-based approach when managing the performance of DSTs. NGET operate in excess of 200 DSTs (Chapter 5, 5.2). These have been assessed as having varying business criticality (Table 18). Given the number of DSTs it would not be possible to performance manage them all, and even if it was, if a DST was not business critical it is questionable as to whether this would be desirable.

Through defining the scope and the rules for how the process is applied within *Establishing the context*, the process can be tailored to the risk appetite of the organisation. This includes looking at the probability and consequences of a risk event occurring to determine:

- The level of risk that is tolerable / intolerable in regards to whether they should be included within the scope of a DST performance management system.
- The level of risk that is tolerable / intolerable in deciding whether a DST should have its performance measured.
- The level of risk that is tolerable / intolerable when evaluating the result of a DST performance assessment.

7.4 Verification and Validation of the DST Performance Management Process

Within the Research Design (Chapter 4), the five stage research evaluation plan was presented (Figure 19). Stage 3 verifies and validates the DST Performance Management Process with two NGET subject matter experts.

The specific areas addressed within the evaluation were:

1. Does the process meet the ten approach requirements defined within Chapter 6?
2. Does the process appear logical?
3. Does the process appear workable within the context of NGET?

Similar to the approach defined in Chapter 6, verification and validation was conducted by way of a focus group. This approach was taken as it had previously been found to be both practical and suitable. The focus group used the same NGET subject specific experts. Using the same experts was important as the philosophical stance taken within this research is that people hold differing realities (Chapter 4, 4.4.1). Therefore, using different experts may have introduce complexity when analysing the results.

During the focus group the DST Performance Management Process was presented and the participants were free to ask questions and discuss their views. Following, the participants were asked to individually complete a questionnaire (Appendix C). The use of individual questionnaires allowed the participants to express their own view. At this early stage, understanding the perspectives of the individuals was key.

The results of the questionnaire are presented in Table 30.

Table 30. Process verification and validation questionnaire responses

		Respondent 1	Respondent 2
	Job Title	Information Quality Officer	Analytics Development Leader
1	Does the DST Performance Management Process appear to address the ten approach requirements YES / NO	Yes	Yes
2	The logic of the process seems correct YES/NO	Yes	Yes
3	The process would seem workable within the context of NGET YES/NO	Yes	Yes

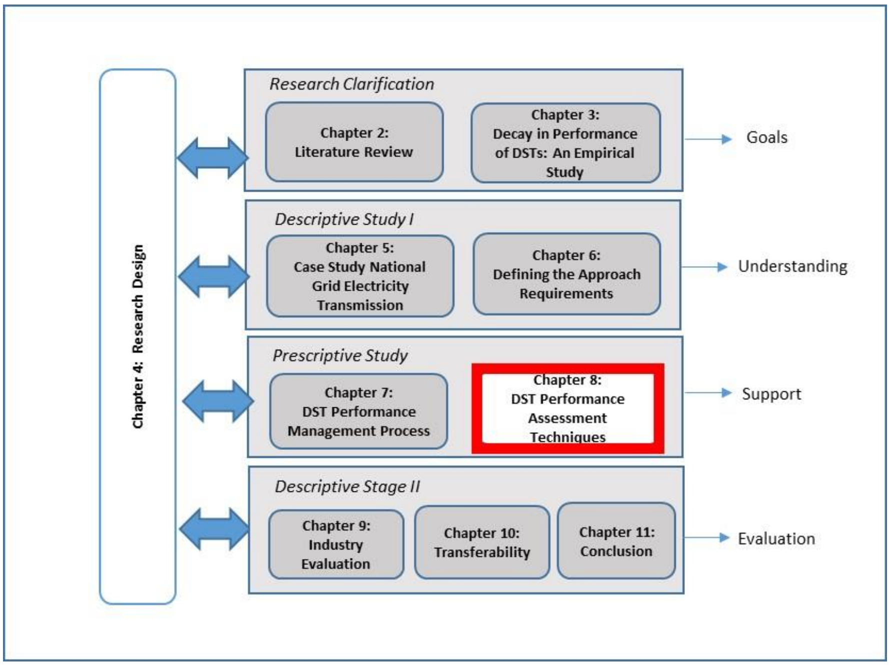
The results showed there to be consensus across all responses. Both considered that the DST Performance Management Process appeared to address the ten approach requirements, and that the process seemed both logical and workable within the context of NGET.

7.5 Chapter 7 – Summary Points

- The DST Performance Management Process is an element within the AM system.
- The process is based on the Risk Management Process found within ISO 31000:2009.
- It provides a novel, risk-based approach for measuring, monitoring, analysing and evaluating the performance of DSTs during their operational life stage.
- The process was evaluated by two NGET subject matter experts. They confirm that it appears to address the ten approach requirements defined within Chapter 6, is logical, and would seem workable in the context of NGET.

Although defining the elements that are conducted within the DST Performance Management Process it does extend to providing the techniques for its practical application. The empirical study (Chapter 3) demonstrates that when measuring performance differing interpretations can be applied. To ensure consistency defined techniques are required. In Chapter 8, the techniques for undertaking the DST Performance Assessment are presented. This includes methods for creating an asset register, identifying the critical DSTs, and measuring the performance of DSTs.

Chapter 8: DST Performance Assessment Techniques



Chapter 7 details the DST Performance Management Process. Although defining the elements, it gave little guidance on how the steps within the DST Performance Assessment should be conducted in practice. This was a potential impediment to industry uptake and could result in inconsistency in how the process was applied.

Chapter 8 defines the techniques for applying the steps within the DST Performance Assessment: Technique 1: Creating a DST register (8.1). Technique 2: Applying a critical rating (8.2). Technique 3: Measuring DST performance (8.3). Finally, summary points highlighting the key findings are provided (8.4).

Figure 46 shows how the techniques relate to the steps within the DST Performance Assessment.

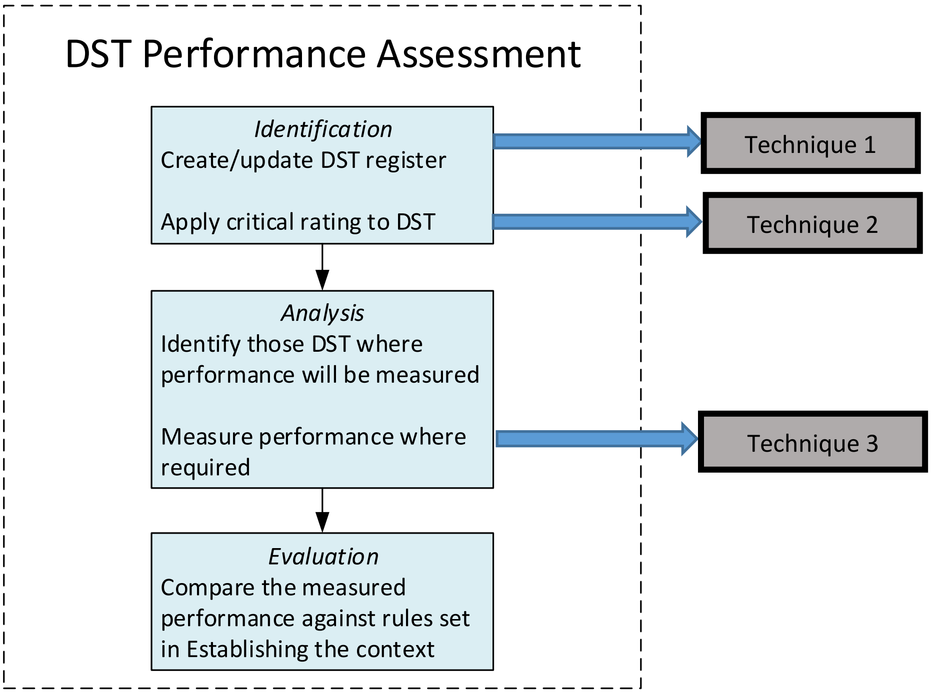


Figure 46. DST Performance Assessment Techniques

8.1 Technique 1: Creating a DST Register

The literature shows that successful Asset Management is dependent on managers having a clear understanding of the assets. Having accurate and up-to-date asset information is fundamental to achieving this clear understanding (Hastings, 2010; Van der Weshuizen and Myburg, 2014; Varadan, 2013). The first step in the DST Performance Assessment is the creation of a DST register. This identifies and provides performance management information for the DSTs that fall within the scope of the process.

Although the steps that an organisation will follow in order to create a register will vary, in order to ensure consistency and allow comparisons both within and across organisations, there should be rules for the information a DST register should contain. Within this section, the basic requirements for the information fields within a DST register are defined. First, it considers whether there are constraints imposed by the ISO 5500x:2014 AM Standard (8.1.1). It then looks to identify what information fields are required, or have been proposed, for asset registers within the academic literature and industry Standards (8.1.2). This background information is combined with the understanding gained during previous research, in order to define the basic information fields required in a DST register (8.1.3 & 8.1.4).

8.1.1 Asset Registers - ISO 5500x:2014 Asset Management

The importance of the ISO 5500x:2014 Asset Management (AM) Standard on how AM is conducted in practice was identified within the literature review (Chapter 2), the case study (Chapter 5), and during defining the approach requirements (Chapter 6). Consequently, the Standard was explored to understand the constraints it might introduce on the creation of a DST register.

Within the Standard there is no formal requirement for an *asset register*, only that the organisation should determine the information needs related to its assets, including its requirements in relation to technical and asset physical properties for example: asset attributes, ownership, design parameters, vendor information, physical location, condition, in service dates (BS ISO 55000 Series: 2014). Any detail on the assets that the organisation gathers is documented and would form part of the organisation's AM system. In effect, the act of documenting this information would create a register of assets.

The information held about the assets is not specified under the Standard but determined by the organisation based on whether the value of the information exceeds the cost and complexity of collecting, processing, managing and sustaining the information (BS ISO 55000 Series: 2014).

The question that this raised was what information should be contained within a DST register. To address this question a review of the academic and industry literature was undertaken.

8.1.2 Asset Registers - Literature

The purpose of consulting the literature was not to conduct and exhaustive review, but as a means of understanding whether asset registers were being used and if so what information might they contain.

Although the general principle of gathering data on the assets was similar, the terminology used to describe this activity varied including creating an asset register (BS 8210: 2012; Hastings, 2010), creating an inventory (Lutz, 2000); undertaking an identification process (BSI ISO/IEC 19770-1: 2012); or documenting assets (BS ISO 55000 Series: 2014). Within this work, asset 'register' is used as the umbrella term for the identification and documentation of organisational assets.

A search on Scopus using the search terms "asset register" or "asset inventory" within the *Article, Abstract or Key Word fields*, and restricted to publications since 2000, returned 151 papers. These papers included a range of subject areas including engineering, computer science, environmental science and social sciences. Within these papers there are examples of asset registers/inventories being used as the initial step within frameworks for bridge maintenance optimisation (Ghodoosi *et al.*, 2018), and managing municipal integrated infrastructure (Abu Samra *et al.*, 2018), and as activities that would be undertaking during the management of infrastructure assets such as roads (Yuan *et al.*, 2017), water (Santos *et al.*, 2017), natural assets such as conservation areas (Brookes, 2015), knowledge based assets (Moreno-Conde *et al.*, 2017), and as part of an information security management system (Białas, 2006). Although the literature provides evidence that asset registers were widely used, they provided little insight into what a 'good' asset register might look like.

Lutz (2000) claims that to manage risk, organisations must know what they own and their condition.   He suggests that this is achieved through an inventory of fixed-assets (i.e. vehicles, office furniture, and IT equipment). In this context *inventory* adopts the generic meaning whereby a 'list', 'catalogue', 'register' of assets is created. The information that it proposes should be contained in this asset inventory/register includes: location, description of the item(s), date of acquisition, and the responsible party.

Likewise, Hastings (2010) claims that for physical asset management (i.e. equipment, plant, buildings and materials), there is value in having a *register* of key assets as it focusses attention on the role and significance of the assets on which the organization depends. Hasting's expands on the limited content identified by Lutz (2000), claiming that organisations should not only include technical detail, but also the business and operational context of the assets. Although, a definitive content list is not provided, it is suggested that the following areas might be included:

- Asset / Capability title
- Brief configuration detail
- Location
- Age
- Estimated remaining life
- Cost
- Replacement cost
- Recent history e. g. last overhaul or upgrade date
- Known issues
- Known plans

Similar to Lutz (2000) the location, description, and date of acquisition (age) are identified as key information to capture. Where the two differ is that first Hastings (2010) does not look to identify the party who is responsible for the asset. This is perhaps explained by the different asset types and whereas it might be possible and pertinent to identify the responsible party for a desk, or photocopier, it might not be as relevant and/or appropriate when looking at a dam, or length of rail track. Second, the register does more than identify the assets; it also captures maintenance information and strategic plans for how the asset will be treated in the future.

It is not only within the academic literature that there is support for the capturing of asset information; it is also a requirement of some International Standards. The creation of an asset *register* is a requirement of ISO 8210:2012 Facilities Management Standard (BS 8210: 2012). A facility is a tangible asset that supports an organisation and can include for example land, buildings, office furniture and IT equipment. The Standard is not prescriptive over what information should be included in the register, but provides a list of 22 items that an organisation might choose to include. These 22 can be broken down into three main categories: identification, operational management, and financial accounting:

- **Identification** e.g. unique identifier, make, manufacturer, vendor, date of manufacture, specification, location, date of acquisition (installation or completion) of construction.
- **Operational Management** e.g. initial costs, predicted lifetime, replacement cycle, maintenance requirements, servicing requirements, maintenance costs, whether or not access equipment is required, whether or not permits-to-work are required, source of spare parts, energy consumption, identification of hazardous or other risk to people or property.
- **Financial Accounting** e.g. written down value, accumulated depreciation.

Similar to Hastings (2010), it can be seen that both asset and operational information are captured within the register. Unlike Hastings (2010) there is no proposal to capture strategic plans for the assets (known plans), but does identify that financial accounting might also be included.

Although the three examples suggest that the identification of assets is restricted only to physical assets, this was found not to be the case. Examples of registers being created for non-physical assets, such as software and information, were also identified. The International Standard for Software Asset Management BS 19770-1 (BSI ISO/IEC 19770-1: 2012) defines the process for Software asset management as: identification, inventory management, and control. The first stage in this process, software asset identification, ensures that the necessary classes of assets are selected, grouped, and defined by appropriate characteristics to enable effective and efficient control. In effect, it creates a register of an organisation's software assets in which the software is categorised by type. Again, within BS 19770-1 the information that is captured within the register is not constrained. However, there are seven basic requirements:

- Unique identifier
- Name/description
- Location
- Custodianship (or owner)
- Status (e.g. test/production status; development or build status)
- Type (e.g. software, hardware, facility)
- Version (where applicable)

The information contained within a software register shares similarities with those suggested when creating a register for physical assets i.e. name / description, location. However, specific to the context of software, there are also categories that have not previously been identified i.e. status and version.

Similarly, the International Standard for Information Security ISO 27001: 2017 (BS EN ISO-IEC 27001: 2017, 2017) has a requirement that in the control of organisational information an inventory of assets should be created and maintained. The assets included in this register are: information, other assets associated with information, and information processing facilities. Therefore, the register combines both physical and non-physical assets. Although the Standard does not provide detail on the information which will be held on each of these assets it stipulates that the register should identify who is responsible for the asset.

The literature showed that asset registers are used in the management of both physical and non-physical assets. Indeed, the creation of an asset register is a requirement within some International Management Standards including facilities, software, and knowledge security management. The information that might be contained within them is not fully defined, suggestions are made and in the case of ISO 19770-1, basic requirements are stipulated. Table 31 presents a comparison of the fields specifically identified within the reviewed literature.

Table 31. Comparison of asset register fields

Asset Register Fields	Lutz (2000) Facilities	Hastings (2010) Physical Assets	ISO 8210 (2012) Facilities	ISO 19770-1 (2012) Software	ISO 5500x (2014) Asset	ISO 27001 (BSI, 2017) Information Security
Identification						
Name / Description / Type	X	X	X	X	X	
Location	X	X	X	X	X	
Date of acquisition / Age	X	X	X		X	
Custodianship (or owner)	X			X	X	X
Unique Identifier			X	X		
Manufacturer / Vendor			X		X	
Status				X		
Version				X		
Operational Management						
Brief configuration detail		X				
Estimated remaining life		X	X			
Condition					X	
Maintenance requirement date		X	X			
Purchase cost		X	X			
Replacement cost		X				
Maintenance cost			X			
Recent history e. g. last serviced		X				
Maintenance work constraints			X			
Spare parts supplier			X			
Known issues		X				
Known plans		X				
Energy consumption			X			
Hazards / risks to people or property			X			
Financial Accounting						
Written down value			X			
Accumulated depreciation			X			

From the literature, the following key points were identified:

1. Within both academic literature and industry Standards there is support for the creation of asset registers.
2. Asset registers can be used both for physical and non-physical asset types.
3. The information contained within an asset register is contextual.
4. Within ISO AM Standard whether to create a DST register, and the information it contains, is determined by the organisation based on cost versus value it provides.

8.1.3 Defining the information fields within a DST Register

The case study showed that although there was not a complete register of all DSTs used within NGET, a register of computer based databases and spreadsheets had been created and was maintained (Chapter 5, 5.5). This suggests that within NGET maintaining a register of DSTs was considered to be of some value.

The information contained within the current NGET register is confined to identification, categorisation, and applying a risk ranking to the DST. It does not capture operational information about the tool. For example, the current performance, or maintenance action planned / taken (Chapter 5, 5.3). The purpose of the DST Performance Management Process is to measure, monitor, analyse and evaluate DST performance. The DST register within the DST Performance Assessment acts as a means of both identifying DSTs, and recording performance management information that will be generated through application of the process. Consequently, it should include data for both DST identification, and operational management.

Figure 47 defines the basic category requirements for a DST asset register as defined by this research. *Identification* combines the information fields commonly found within registers, with the fields required for software asset registers under ISO 19770-1, and proposed within the Asset Management (ISO 5500x) and Facilities Management Standards (ISO 8210). *Operational Management* captures information that will be generated through undertaking a DST Performance Assessment.

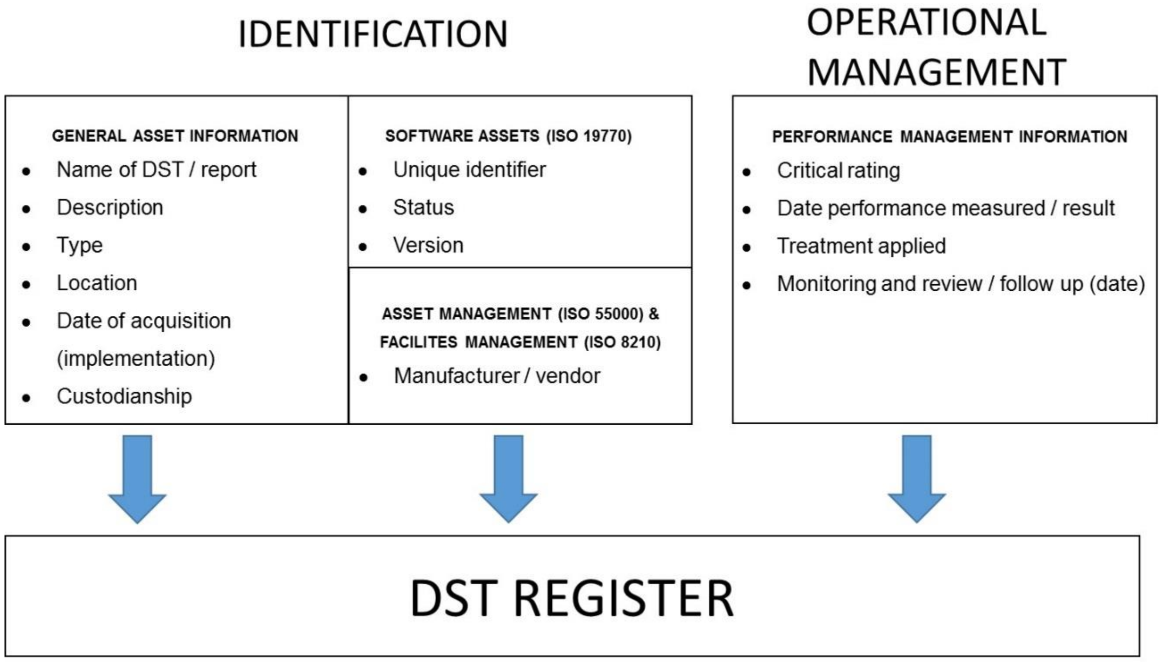


Figure 47. Basic requirements of a DST register

Identification Fields:

Table 31 demonstrates the information fields used to identify assets. Of these thirteen, four are commonly seen, appearing in at least four of the six sources. These are name / description / type, location, date of acquisition (implementation), and custodianship (owner). This general usage was considered to justify their inclusion within a DST register.

A lower level of support was seen for the four remaining categories with them appearing in only one, or two of the five registers. As identified both within the literature review (Chapter 2, 2.2), and the NGET case study (Chapter 5, 5.3), DSTs used within AM will include a range of both manual, and computer based systems. As such, any information fields that were amongst the basic requirements for a software asset register under ISO 19770-1, were considered to have potential relevance. These additional categories were unique identifier, status, and version.

The only remaining field, manufacturer/vendor, was proposed for inclusion within the Facilities Management Standard (ISO 8210), but also within the Asset Management Standard (ISO 5500x). The NGET case study (Chapter 5), highlights that although the Whole Life Value Framework (WLVF), and the Network Output Measures (NOMs) tools were developed internally, the Strategic Asset Management DST was developed by IBM. Therefore, capturing the manufacturer/vendor was considered both relevant and important as it would have potential implications for their operational management (i.e. what treatment might be applied).

Operational Management Fields:

Table 31 showed that registers are being used as a means of capturing operational management information. However, the information that is captured is less frequently defined, and there is less of an obvious consensus than for the information captured to identify assets. Within the six sources, operational information fields were only identifiable within three. Within the ISO AM Standard, the fields were broadly stated as 'configuration detail' and 'condition'. Within the work of Hastings (2010) and the Facilities Management Standard (ISO 8710) the field were more detailed incorporating thirteen different information fields. However, there were only three that appeared in both lists: *estimated remaining life*, *maintenance requirement date*, and *purchase cost*.

Estimated remaining life and *purchase cost* were considered not be appropriate fields for inclusion within a DST register. *Estimated remaining life* was considered too uncertain as it would depend greatly on changes within the internal and external context, which would be difficult, if not impossible to accurately predict. Purchase cost was considered irrelevant because, as identified within the case study, the cost of creating a DST does not necessarily correlate to its criticality (Chapter 5, 5.6).

The first three categories seen with the operational management information fields of the DST register, map to the activities which are conducted when applying a DST Performance Assessment. They capture the outputs of these activities: the critical rating (the approach for which is defined by Technique 2), the date performance was measured and the result (the approach for which is defined within Technique 3), and the treatment action applied.

The forth category reflects the capturing of a *maintenance requirement date*, seen within the example asset registers. Including this category was considered to have relevance as performance management of the DST is intended to be cyclical. To achieve this iterative cycling there needs to be a prompt for rerunning the process. Although relevant, the term *maintenance requirement date* was considered too narrow. A quality-managed process should not only schedule maintenance, but also monitor and review actions taken i.e. review whether the treatment applied had been successful, or whether the criticality of the DST had change. Consequently, an information field of *monitoring and review / follow-up date* was included.

8.1.4 Defining the Type Categories

Figure 47 shows that within the register there is a requirement to identify the DST *type.* The literature identifies that the nature of DSTs means that their management necessitates cooperation across both users, and developers/analysts (Chapter 2, 2.4.2). Defining *Type* categories facilitates cross-functional understanding both within and across organisations. Table 32 proposes a two level classification scheme for categorising DST *Type*.

Table 32. DST Type categories

Type 1 Categories	Type 2 Categories	Description
Manual System	N/A	N/A
Computer based Databases or spreadsheets	Personal Decision Support Systems	Small scale systems that are developed for one manager, or a small number of independent managers, to support a decision task
Customised computerised systems	Business Intelligence	Large-scale systems that use data and analytics to support decision making at all levels of an organization. BI systems are often based on a data ware-house or data mart
	Group Support Systems	The use of a combination of communication and DSS technologies to facilitate the effective working of groups
	Negotiation Support Systems	DSS where the primary focus of the group work is negotiation between opposing parties
	Intelligent Decision Support Systems	The application of artificial intelligence techniques to decision support
	Knowledge Management Systems	Systems that support decision making by aiding knowledge storage, retrieval, transfer, and application by supporting individual and organizational memory and inter-group knowledge access

Type 1 Categories: As identified DSS are a subset of DST (Chapter 2, 2.3.1). Whereas DSS are restricted to computerised systems, DST can be either manual, computer based databases or spreadsheets, or customised computerised systems. The Type 1 categories make this distinction.

Type 2 Categories: The Type 2 categories provide more granularity to computer based DSTs. The categories are based on the typologies proposed within the DSS academic literature, thus adopting a common terminology. Having common understanding across AM and IS will be advantageous in identifying risk and opportunities. For example, it may highlight there to be a risk arising from a database that is not backed-up in an appropriate manner, or an opportunity that could be realised by combining a database tool within an existing customised computerised system.

The academic literature demonstrates that a number of typologies have been proposed through which to categorise DSS (Chapter 2, 2.4.1). Within these works the typology proposed by Arnott and Pervan (2014) was selected as it was the most recent of the approaches created (and thus more likely to align with new technology), and had been extensively empirically tested being used in a literature review which categorisation more than 1400 DSS articles, published over an extended period from 1992 – 2010 (Arnott and Pervan, 2014).

Although, standardised *Type* classifications are proposed, it is recognised that organisations may have a need, or desire to continue with or create their own classification schemes. Should additional classifications be required these should be in addition, rather than in replacement of the classification scheme defined within these works.

8.2 Technique 2: Applying a critical rating

The case study showed that NGET have in excess of 200 DSTs (Chapter 5, 5.2). Of these some are considered by the organisation to be business critical (i.e. Network Output Measures DST), some have both business critical and non-business critical applications (i.e. Strategic Asset Management DST), whilst for others their criticality is unknown (i.e. Whole Life Value Framework). It would not be practical, or perhaps desirable, to measure the performance of every DST. A method is required to identify which DSTs are the most critical. Then, through the rules defined in *Establishing the context*, management effort can be focus on those with the highest priority.

This section defines how a DST critical rating is applied (Technique 2). First, it considers whether there are constraints imposed by the ISO AM Standard for how criticality is assessed (8.2.1). It then looks to identify techniques used for identifying critical assets found within the literature (8.2.2). Following, how critical asset analysis is used within the UK electricity transmission sector (8.2.3). By combining this understanding with that gained previously within the project research, the technique for applying a DST critical rating is defined (8.2.4).

8.2.1 Critical Asset Analysis - ISO 5500x:2014

Within the ISO AM Standard a critical asset is defined as one having the potential to significantly impact on the achievement on the organization’s objectives (BS ISO 55000

Series: 2014). Under the Standard, the criteria used in critical asset analysis is not confined to purely financial measures but can extend to safety, environment or performance, and can relate to legal, regulatory or statutory requirements (BS ISO 55000 Series: 2014).

In keeping with the non-prescriptive approach taken within the Standard no method or technique for undertaking a critical asset analysis is provided. However, it is suggested that a risk ranking process might be used (BS ISO 55000 Series: 2014).

With the AM Standard providing little insight the review turned to the literature for guidance.

8.2.2 Critical Asset Analysis – Literature

It is widely accepted that when planning and prioritising asset management actions you need to understand the criticality of your assets (Crespo Márquez *et al.*, 2016; Marquez, 2007; Moss, 1999; Varadan, 2013). Healy (2006) suggests that a variety of techniques can be used in critical asset analysis. These can range from a 'wild guess', to fully quantitative risk assessments based on probability and consequences of a failure (Healy, 2006). Each technique will have advantages and disadvantages with the choice being ultimately dependent on the purpose and context of the analysis (ENISA, 2014; Healy, 2006; Marquez, 2007).

Although recognising that a multitude of techniques are available Marquez (2007) categorises these into three main approaches: qualitative techniques, Analytical Hierarchical Processing (AHP), and a risk assessment technique. A description and the strengths and weaknesses of each are summarised within Table 33.

Table 33. Main approaches for critical asset analysis (Crespo Márquez, 2007)

Approach	Description	Strengths	Weaknesses
Qualitative Techniques	Gathers stakeholder inputs and makes a critial asset assessment based on their opinions, and experience	Quick, simple, ease to understand. Does not require access to quantitative data.	Can be unstructed and inconsistent. When used in conjunction with flowchart results in a rating rather than prioritised list of critical assets.
Analytical Hierarchical Processing (AHP)	Pairwise comparison of assets which links the goal, objectives (criteria), sub-objectives and alteratives	Structured. Can incorporate both intangible and tangible criteria. Hierarchy can be designed to align to the objectives of the organisation. Output is a prioritised list of critical assets.	Costly to create hierarchy, and to making the pairwise comparisons. End result is a prioritied list of assets it does not determine how critical the assets are.
Risk Assessment Technique	Analysis based on a formula of probability and consequence of a risk event occuring	Structured. Results in a criticality rating for each asset.	Dependent on availability of historic data. Focus is on risk as a negative. Would not identify potential opportunities.

Qualitative Techniques gather inputs from a range of stakeholders and identify the critical assets based on opinions and experience. The advantages of taking a qualitative rather than quantitative approach is that it is quick to accomplish, simple to understand, and is not dependent on having access to quantitative data. The disadvantages are that without due diligence assessments can be unstructured, and there can be inconsistent rating as participants interpret terms used in assessments differently (Marquez, 2007).

To introduce a more systematic approach qualitative techniques can be used in combination with flowcharts (Marquez, 2007).

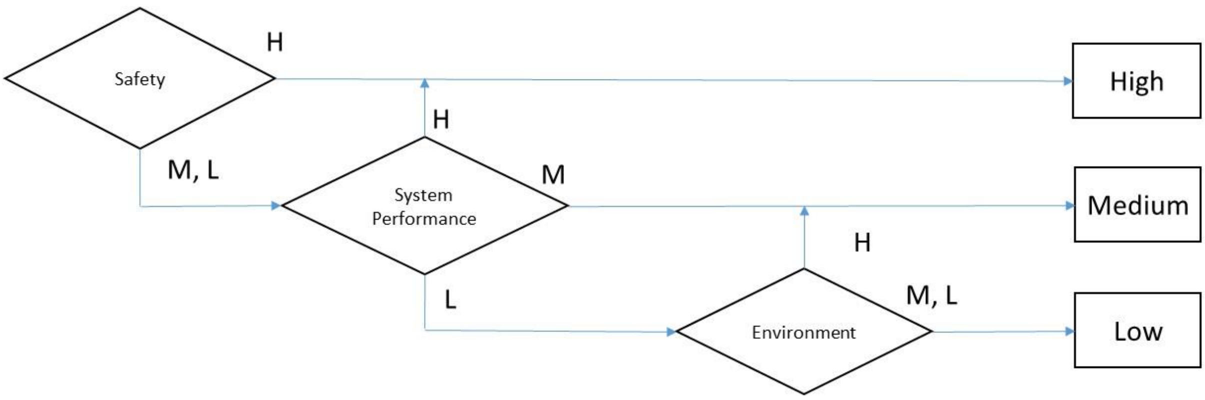


Figure 48. Constructed example of a critical asset analysis flow chart

Figure 48 is a contructed example of a critical asset analysis flowchart. The asset is assessed under three criteria: safety, system performance, and environment. Based on the qualitative inputs of stakeholders the criticality of the asset is graded as High (H), Medium (M), or Low (L) under each element. This grading determines the route which is followed and the overall critical rating applied (High, Medium, or Low).

Analytical hierarchical processing (AHP) uses a hierarchical structure to model a problem which links the goal, objectives, sub-objectives and alteratives (Figure 49). Based on this hierarchy, pairwise comparisons are made (typically using expert judgement) for each of the criteria. These pairwise comparisons are translated into numercial values allowing comparisons to be made.

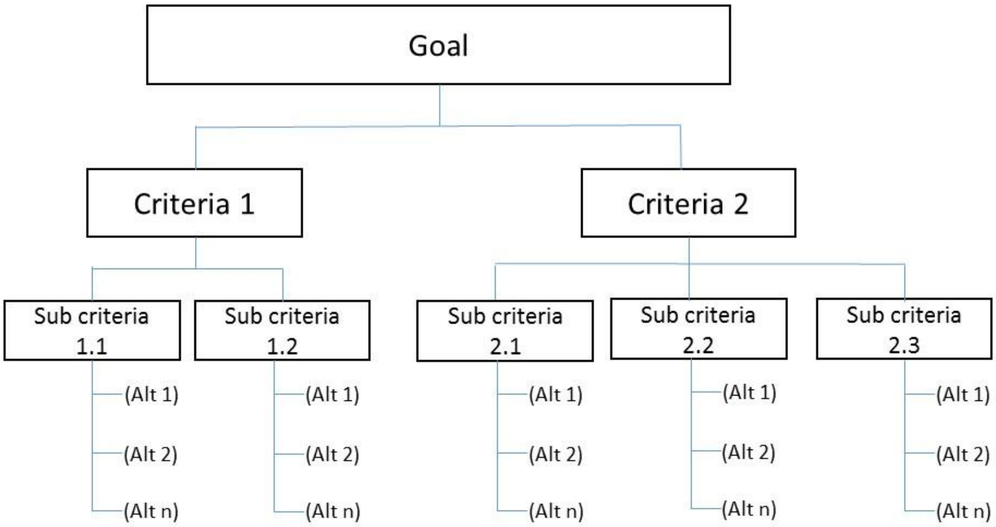


Figure 49. Example of decision hierarchy (Marquez, 2007)

This approach provides a structured means of incorporating intangible and tangible criteria during critical asset analysis. Through the creation of this hierarchy it is possible to align the criteria against which the asset is assessed to the objectives of the organisation. The end result of this approach is a prioritised list of assets (Marquez, 2007).

The weaknesses of the approach is that it is costly in terms of the time involved in creating and updating the hierarchy, and in making the pairwise comparisons. Furthermore, the end result is a prioritied list of assets based on how each asset compares to another, rather than how they compare to the specific assessment criteria. Therefore, it is possible that even the highest ranking asset would still not be at a level at which the organisation would want to manage its performance. Likewise, the lowest rated asset might also exceed an organisation's risk tolerance level.

Risk Assessment Technique uses a formual based on probability and the consequences of a risk event occuring to arrive at a criticality (risk) score. Within the literature this technique is sometimes described by the term *criticality analysis*.

The use of this approach for prioritising the maintenance of assets is long established and widespread (Crespo Márquez *et al.*, 2016; Marhaug *et al.*, 2017; Moss, 1999; Varadan, 2013). Although qualitative inputs can be used, risk based criticality analysis is often highly quantitative and numeric. In this case $R= PxC$, where R is an individual risk event, P is the probability, and C is the consequence. The total risk (criticality) is the sum of the individual risk classes.

The strengths of this approach is that it is structured and results in a criticality score or ranking for each asset. This is as opposed to the prioritised list of assets which is created through AHP. The organisation is therefore able to determine the level at which risk becomes intolerable. The weaknesses are that to undertake a risk based criticality analysis requires some understanding as to the probablity and consequences of a risk event occuring. This can be difficult and/or costly to acquire. Furthermore, this technique results in an assessment based on a negative risk event occuring. It would not identifying opportunities to increase the value being realised from a DST. For example, the NGET case study suggests that the WLVF DST might not be used as extensively as it could be be (Figure 27). This is unlikely to represent a significant risk for the business. Alternate governance processes within the organisation would mitigate against both the possibility and the consequences of a risk event occuring. However, if it was used more, there is the possibility that additional organisational value might be realised. There is an opportunity for additional value to be realised.

The review identified three techniques for assessing the criticality of the assets seen within the literature. It then sought to understand how the criticality of assets was being assessed within the UK electricity transmission sector.

8.2.3 Critical asset analysis within the UK electricity sector

As detailed within the NGET case study, the UK electricity transmissions sector must submit annual reports to the UK regulator (Ofgem) on the health and criticality of key assets within the network (Chapter 5, 5.4.2). The key assets are: circuit breakers, transformers, reactors, overhead lines, underground cables.

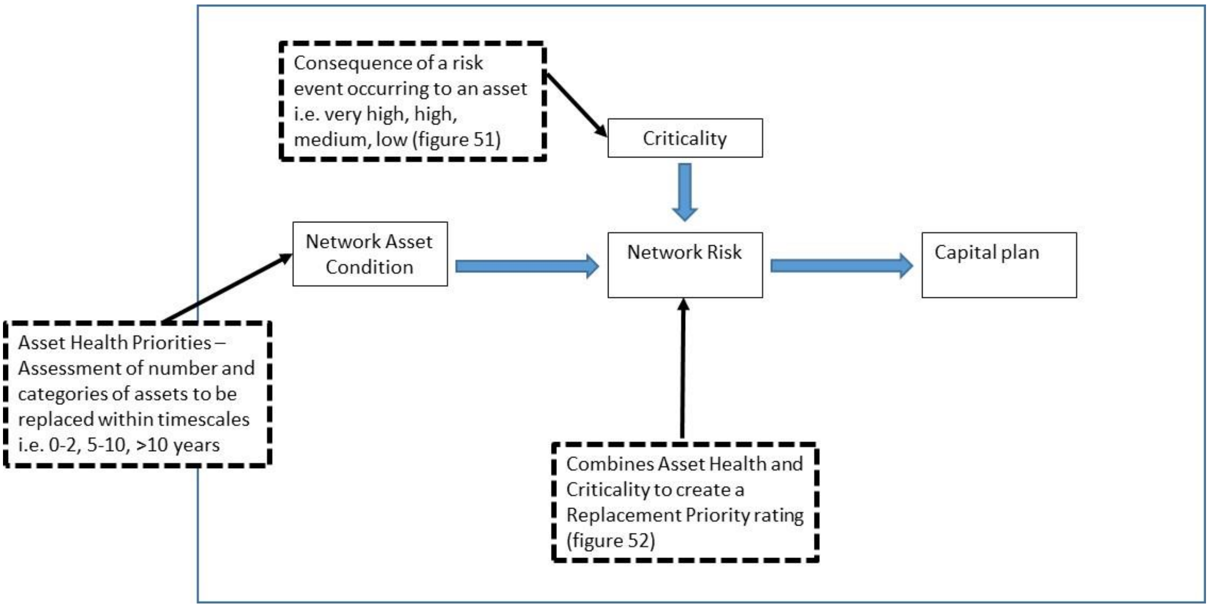


Figure 50. Use of asset criticality with NGET regulatory reporting

Figure 50 shows the process of creating this report. First, the condition of the assets within the network is assessed. The asset health priorities are the number and categories of assets to be replaced within a specific timescale (i.e. 0-2, 2-5, 5-10, >10 years). This assessment is based on objective data about the current asset condition, and models which predict how the asset will degrade under specific maintenance interventions.

Next the risk to the network is assessed. Within this area 'criticality' is the consquence of a risk event occuring. It considers three factors: safety, reliability, and environment. Figure 51 presents the matrix used in assessing the 'criticality' of the asset with regulatory reporting. Although in assessing the health of the assets the methodology is clear to point out that objectives data is used, the basis on which assessments of asset 'criticality' are made (the consequences of a risk event occuring), is less clear. However, given the criteria which are considered an assumption was made that this would be subjective rather than based on objective analysis of data.

	System		Safety		Environment
Very High	N/A	OR	Failure of asset may result in fatality. Constant personnel/public activity within vicinity of asset	OR	N/A
	IF NONE OF THE ABOVE CRITERIA ARE APPLICABLE				
High	Vital infrastructure: {Economic key point; Supporting Major Traffic Hub; COMAH Site; Black Start Site; Supports Nuclear Generation} or Substation Demand ≥ 600MW; System Security = High	OR	Failure of asset may result in permanently incapacitating injury. High levels of personnel/public activity within vicinity of asset.	OR	Failure of asset may lead to reportable environmental incident which may result in prosecution. Asset located within proximity of environmentally sensitive area.
	IF NONE OF THE ABOVE CRITERIA ARE APPLICABLE				
Medium	Substation Demand = 300-600MW or System Security = Medium	OR	Failure of asset may result in reportable injury. Regular personnel/public activity within the vicinity of asset.	OR	Failure of asset may lead to significant environmental incident with agency visibility. Asset located in controlled area or distributed asset not within proximity of sensitive environment
	IF NONE OF THE ABOVE CRITERIA ARE APPLICABLE				
Low	Substation Demand ≤ 300MW and System Security = Low	AND	Failure of asset results in minor or no consequence. Limited personnel access. No likely public access.	AND	Failure of asset may lead to minor environmental incident (without agency visibility) that can be managed locally or no environmental consequence. Asset located in controlled area.

Figure 51. Asset criticality mapping within Ofgem regulatory reporting (National Grid, 2010)

The result is a 'criticality' rating of one of four levels (very high, high, medium, low). Therefore, within the methodology 'criticality' is an assessment of the consequences of a risk event occuring, rather than the combined outcome of the probability and consequences of a risk event occuring which is commonly seen within the literature.

The health and the 'criticality' of the asset are combined to give a replacement priority rating (Figure 52). In effect the replacement priority considers the likelihood and consequences of a risk event. In this way it is akin to the risk assessment technique detailed within the literature (8.2.2).

Asset Health Index (replacement in years)	**Criticality** Very High	High	Medium	Low
0 - 2	Priority 1	Priority 1	Priority 2	Priority 2
2 - 5	Priority 1	Priority 2	Priority 3	Priority 3
5 - 10	Priority 3	Priority 3	Priority 3	Priority 4
10+	Priority 4	Priority 4	Priority 4	Priority 4

Figure 52. Asset health/criticality to determine replacement priorities. National Grid (2010)

However, as identified regulatory reporting is not required against all assets. Only the five asset types which are considered key within the electricity network are included. Therefore, within the electricity transmission regulatory critical asset analysis has two levels. First the *critical assets* were identified. These are the assets which are considered to have the most value within the electricity transmissions network. Second, the critical assets are subjected to *criticality analysis* to assess the probability and consequences of a risk event occuring. The output of this analysis informs capital investment and strategic planning.

8.2.4 Defining the technique for applying a critical rating to DSTs

Within the regulatory reporting there are two levels used in critical asset analysis: identify the critical assets, and criticality analysis. Likewise the DST Performance Management Process has two levels. Figure 53 shows how these two level are positioned within the DST Performance Assessment. First within the identification step the critical DSTs are identified. Then only if necessary a criticality analysis is conducted as part of the treatment step.

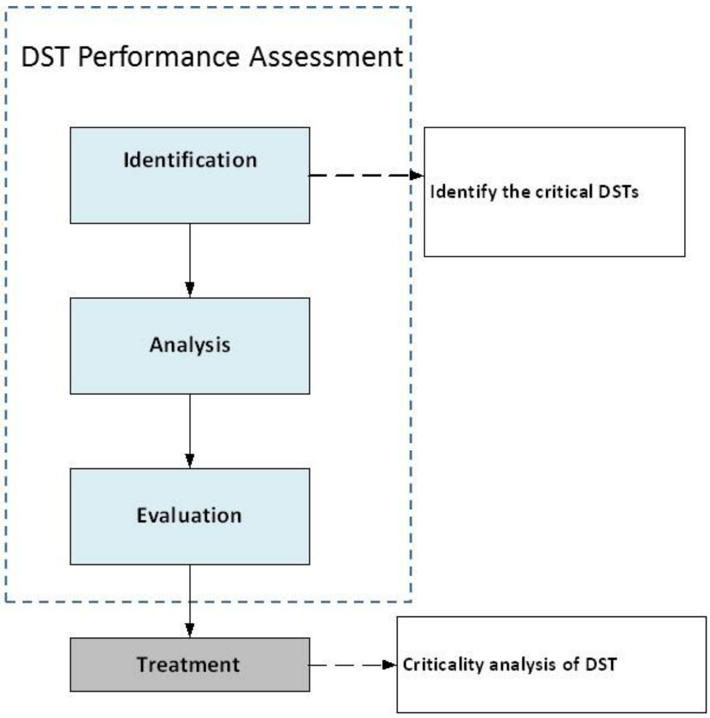


Figure 53. Critical asset analysis within the DST Performance Assessment

The reasoning for this approach follows. The purpose of applying a critical rating within the *identification* step of the DST Performance Assessment, is to identify which DSTs have the greatest potential or actual value within the organisation. Based on this assessment and by applying the rules defined within the *Establishing the Context* element, the *analysis* step identifies those DST where the performance will be measured. In effect it assumes a risk-based approach whereby not all DSTs will have their performance measured, only those which have the greatest actual or potential value.

The result of the performance measure (and in accordance with the rules defined within the *Establishing the context* element) will determine which of a range of treatments is applied. One possible treatment might be to conduct a criticality analysis for the DST. That is, to look at the probability and consequences of a DST not performing. This being the case the performance result, obtained from measuring the DST performance can be used as an input into the criticality analysis. Conducting the criticality analysis may be undertaken within the DST Performance Management Process, but equally might be conducted under a separate but integrated risk management process/system.

The benefits of first identifying the critical DSTs and only if required undertaking a criticality analysis are:

- Identifying the critical DSTs is quicker than conducting a criticality analysis. It provides a rapid and efficient means of reducing the scope.
- Criticality analysis identifies those DSTs which have the greatest risk to an organisation. However, AM is not only about risk but also opportunity. Identifying the critical assets based on their potential or actual value would highlight not only those with the greatest risk, but also the greatest opportunity.
- To conduct a criticality assessment requires an understanding of the probability and consequence of a risk event occuring. Within NGET this data would not be readily available (Chapter 5, 5.3). By measuring the performance of a DST it provides an means of generating data which would be an input into criticality analysis.

Having identified that it is the critical assets that are identified within the *identification* step of the DST Performance Assessment, the question remains on how this should be achieved. Although this approach has been used within the regulatory reporting, the technique used to identify the critical assets was not documented within the methodology (National Grid, 2010). Furthermore, although Marquez (2007) identifies that qualitative assessments of the critical assets can be undertaken based on expert input, no further guidance is provided.

The concept map created within the literature review (Figure 11) identified that AM is concerned with the realisation of value from assets which contributes towards the organisational objectives. Additionally, that within AM alignment of the asset management policies, and processes is a fundamental principle that underpins the AM Standard (Chapter 6, 6.3.2). Consequently, when identifying the critical DSTs the criteria that are used within the assessment should align to the organisational objectives.

8.3 Technique 3: Measuring DST Performance

Although there are numerous theoretical approaches, there is a lack of consensus on how to measure the performance of assets within the infrastructure sector (Australian Government Department of Infrastructure and Regional Development, 2017). Specifically, neither the academic nor the industry literature define a 'good' practice approach for measuring the performance of DSTs used within an asset management context (Chapter 2).

Technique 3 addresses this gap. Within this section, it first considered whether and what constraints the ISO AM Standard imposes on how DST performance is measured (8.3.1). With the Standard giving little direction, it compares approaches for measuring asset and information system (IS) performance found within the literature (8.3.2). A model for measuring the performance of DSTs, based on the Delone and McLean Model of IS Success, is proposed (8.3.3) and the individual metrics used within the model defined (8.3.4).

8.3.1 Measuring Performance – ISO 5500x:2014 Asset Management

As stated previously, The International Organization for Standardization define performance as a 'measurable result'. In the context of the AM Standard, this 'measurable result' is in relation to the value it contributes towards achieving organisational objectives (Chapter 3, 3.1.1).

Within the ISO AM Standard, there is no specific requirement to measure the performance of DSTs. However, it does state that there should be systematic measurement, monitoring, analysis and evaluation of the performance of organisational assets (BS ISO 55000 Series: 2014). This research advocates that DSTs are organisational assets and as such should be subject to the same performance management.

The AM Standard does not attempt to define what asset performance measurements should be, or how they should be made, only that:

- They can be qualitative or quantitative, financial or non-financial.

- They should identify both successes and areas requiring action.
- The organisation should consider the alignment between performance measures (BS ISO 55000 Series: 2014).

With the Standard providing little direction, the research looked to the literature for further insight.

8.3.2 Measuring Performance – Literature

Performance measurement is the process of establishing the efficiency and effectiveness of action (Neely *et al.*, 2005). Traditionally, measures of performance have been based on financial criteria considering measures such as profitability, return on assets, and/or return on equity (Neely *et al.*, 1997; Nudurupati *et al.*, 2011). However, basing performance measurements on financial criteria has limitations. Notably, within an AM context performance measures should align to organisational objectives. The challenge with this is that organisational objectives are often be difficult to monetise. This is supported by the NGET case study. Although there are a number of financially based Key Performance Indicators (KPIs), there are also measures against which it would be challenging to place a financial value e.g. customer satisfaction, employee injury rates, and greenhouse gas reduction.

To accommodate broader measurements of performance an extensive number of frameworks, models, tools and techniques have been proposed e.g. The Performance Measurement Matrix (PMM), The Balanced Scorecard, The Results and Determinants Framework, The Performance Pyramid, and the Performance Prism (Bititci, 2015; Neely *et al.*, 2005). These expand categories of performance measures to include customer / employee satisfaction, benchmarking against competitors, etc.

Although, regulatory requirements and Standards have seen a convergence in how performance is measured in some sectors, recent research conducted by the Australian Governments highlights that within the infrastructure sector different approaches persist (Australian Government Department of Infrastructure and Regional Development, 2017). They identify that performance measurement of infrastructure assets is ‘patchy’, with systems and measures varying across states and territories. As an initial step towards achieving consistency, a common framework for the measuring of infrastructure asset performance was developed (Figure 54).

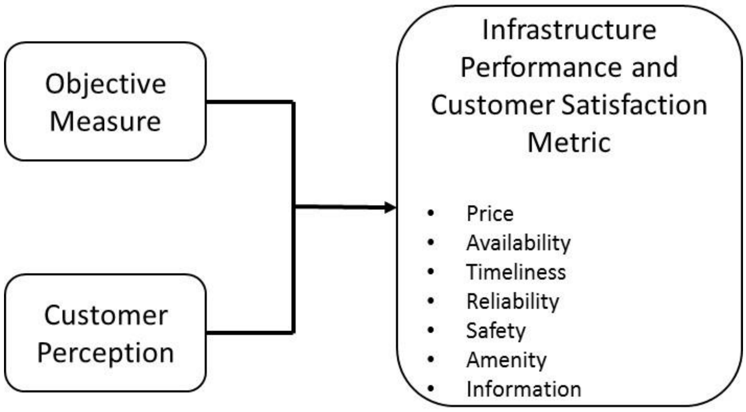


Figure 54. Infrastructure performance and customer satisfaction metric flow diagram

The approach proposes that performance measures should be a mixture of objective indicators (i.e. a measure of road surface quality), and a subjective customer satisfaction indicator (i.e. a survey of road user perception of road surface quality). The need to combine both indicators derives from the argument that although customers are best placed to rate their satisfaction, many factors which are important to the service quality are invisible to the customer and are only apparent once a defect arises.

Although this research advocates that DSTs are assets, it accepts that they bear a limited resemblance to engineered infrastructure assets. The NGET case study identified that DSTs were predominately computer-based systems.

The Delone and McLean Model has made a significant contribution to the theory of IS performance measurement (DeLone and McLean, 1992; DeLone and McLean, 2003). Indeed, in the 15 years prior to 2009 it was the most highly cited IS article in the world (Petter and McLean, 2009). The popularity of the Model persists and in recent years it has been applied to measure the performance of all manner of IS systems including virtual education systems (Mahmoodi *et al.*, 2017), mobile business banking services (Al-Ghazali *et al.*, 2015), business to consumer systems (Rouibah *et al.*, 2015), hospital information systems (Mobasheri *et al.*, 2014) and a DSS used within Royal Jordanian Airlines (Alshibly, 2015).

DeLone and McLean's first paper on this subject (DeLone and McLean, 1992) built on previous work of Shannon and Weaver (1949) and Mason (1978). Shannon and Weaver, identified there to be three levels at which people assessed IS performance: *technical, semantic*, and *effectiveness* or *influence*. Within this paper t*echnical* is the accuracy and efficiency of the system, *sematic* is the ability of the system to convey its intended meaning, and *effectiveness* is the impact of the information on the user. Mason (1978) extended work in this area by proposing that there was a serial flow of information through a system – production, product, receipt, influence on recipient, and influence on system. DeLone and McLean concluded that IS success was a multidimensional and interdependent construct and that it was therefore necessary to study the relationships between variables (DeLone and McLean, 1992). The six interdependent categories they proposed were: *System Quality, Information Quality, Use, User Satisfaction, Individual Impact, and Organisational Impact* (Figure 55).

Shannon and Weaver (1949)	Technical Level	Semantic Level	Effectiveness or Influence Level			
Mason (1978)	Production	Product	Receipt	Influence on Recipient		Influence on System
Delone & McClean (1992)	System Quality	Information Quality	Use	User Satisfaction	Individual Impact	Organizational Impact

Figure 55. Categories of IS Success (DeLone and McLean, 1992)

These categories were then developed in to a model Figure 56 presents the Delone and McLean Model of IS Success which combines objective technical criteria, and subjective customer perceptions.

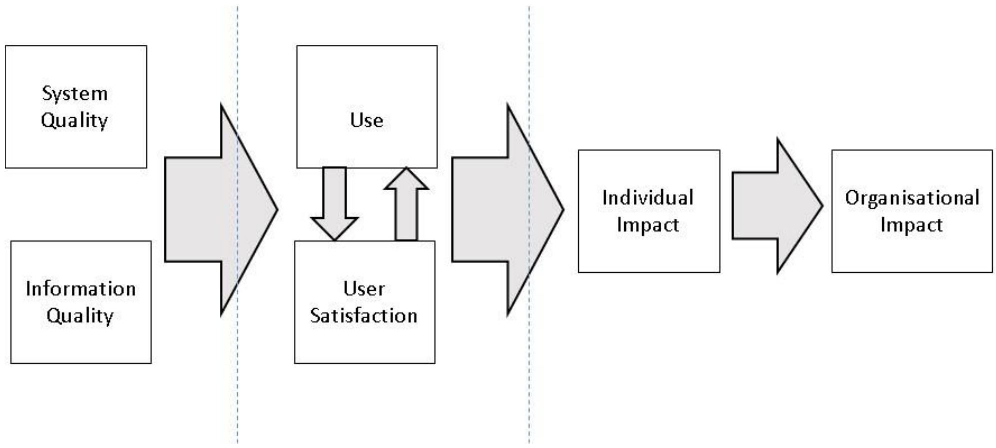


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Figure 56. DeLone and McLean Model of IS Success (DeLone and McLean, 1992)

The Model proposes that an IS system is first created. This system will possess a level of system and information quality. Following, the user will experience the system and will be either satisfied, or not, with the system and/or its information. The use of the system / information affects or influences the user in their work, which results in individual and then organisational benefit.

In the years following publication the DeLone and McLean model was subjected to extensive academic testing. In 2003 DeLone and McLean analysed the results of these studies and enhanced the model to incorporate new learning, and to reflect the changing operational and organisational environment (DeLone and McLean, 2003). The enhanced 2003 DeLone and McLean Model of IS Success proposed seven variables: I*nformation Quality, System Quality, Service Quality, Intention to Use, Use, User Satisfaction, and Net Benefits* (Figure 57). Although similar, the updated model included a new variable of *Service Quality*; combined individual and organisational impact into one generic variable of *Net Benefit*; and offered an alternative of *Intention to Use to* address the academic debate of whether the variable should measure behaviour (*Use*) or attitude (*Intention to Use*).

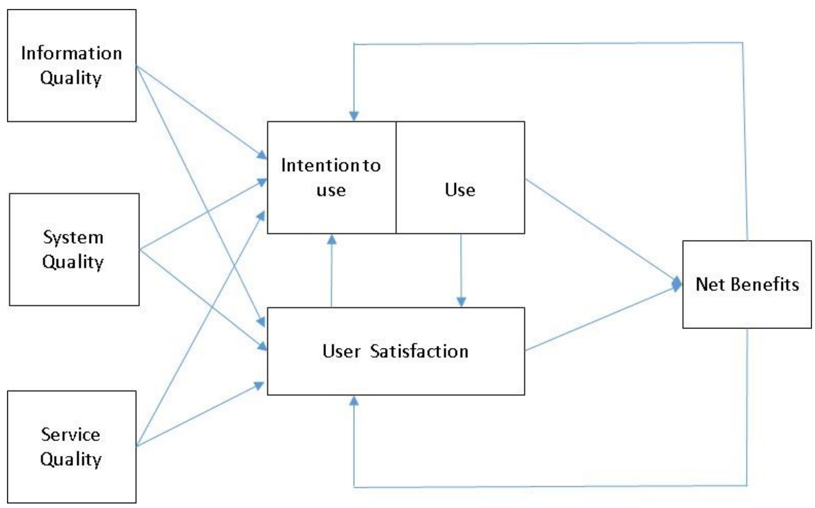


Figure 57. DeLone and McLean Model of IS Success (DeLone and McLean, 2003)

Comparing the infrastructure performance metric flow diagram and the Delone and McLean model shows that both use multiple measures to arrive at an overall assessment of performance. Where the two differ is that rather than combining technical and customer measures (as seen in the infrastructure model), the variables are presented as a flow with technical quality having a causal effect on user satisfaction and use.

8.3.3 Defining the DST Performance Measurement Model

The technique for measuring DST performance was created based on an adapted version of the Delone and McLean Model of IS success. Although the literature showed that there were a number of approaches which might have been used, the Delone and McLean Model had withstood extensive academic scrutiny, and with the exception of *Service* Quality, the connections between the variables had extensively empirically validated (Petter and McLean, 2009). This would imply that for variables where DST performance data was missing, performance might be predicted (if not proven). Furthermore, upstream variables might be targeted with action in order to improve predictions of downstream performance.

If this theory were found to hold, it would be of particular benefit when measuring DST performance. First, measuring DST performance was not established practice within AM. It was expected that initially there would be limited data available under each of the categories. Second, identify the *Net Benefits* of selecting an asset, or management regime, is complex. Often benefits are interconnected, intangible, or subject to a lag and as such difficult or costly to assess. Although DeLone and McLean (2003) warn that *Use* and *Satisfaction* cannot be used as alternatives to measuring *Net Benefit,* they argue that underperformance in these areas would be an indicator that issues might exist.

Creating the model was undertaken in two-step: First, the model categories were defined (stage 1). Next, the method and subcategories to be measured under each of the categories were defined (stage 2).

Stage 1: Defining the Model Categories

Figure 58 presents the first stage in creating the DST Performance Measurement Model. It model includes five categories: *System Quality, Information Quality, Use, Satisfaction and Net Benefits*. The two adaptions from the Delone and McLean model were:

- Removal of *Service Quality* category.
- Inclusion of *Use* Rather Than *Intention to Use*

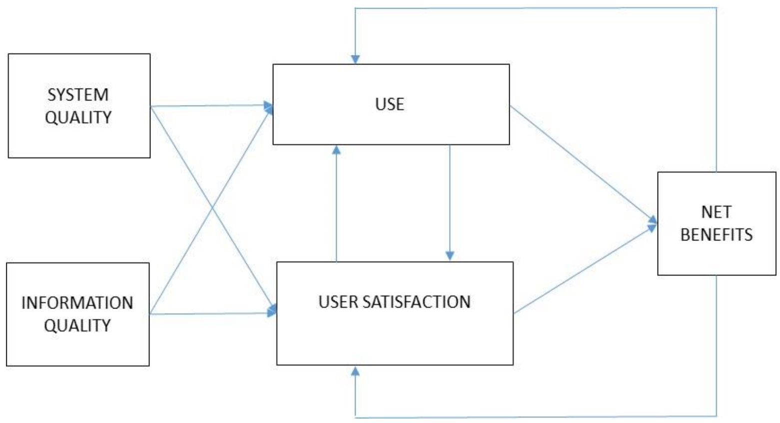


Figure 58. Stage 1: DST Performance Measurement Model Categories

Removal of *Service Quality* Category

As stated previously (8.3.2) *Service Quality* was not seen in the first Delone and McLean Model, but added to the updated 2003 version as part of the academic review. The addition of this category was in response to claims that IS organisations had a dual role of information provider (providing an information product) and service provider; yet, the original model focussed on the product rather than the overall service of the IS department. The introduction of the *Service Quality* category was an attempt to overcome this challenge. However, in doing so it was recognised that *System Quality* is more likely to be used in measuring the performance of an IS department, rather than an individual system. Ultimately the specification and application of the IS Success Model is determined by the context – what the model is trying to measure (DeLone and McLean, 2003).

A meta-analysis of 52 separate validation studies was conducted in 2009 (Petter and McLean, 2009) included *Service Quality* variables introduced in 2003. The results proved there was a connection between all the variables tested except between *Service Quality* and *User Satisfaction*, and *Service Quality* and *Use* – where the connections were considered "not significant" - and *Service Quality* and *Intention to Use* – where there was insufficient data available to test. Thus, although there was empirical evidence of the validity of all other aspects of the Model, the connection between *Service Quality* and the other categories was not proven.

After considering these findings, the *Service Quality* category was excluded from the DST Performance Management Model.

Use Rather Than *Intention to Use*

Within the earlier 1992 DeLone and McLean Model the category of *Use* was seen. The updated model altered this category to that of both *Use* and I*ntention to Use*. The reason for this change was to respond to academic arguments that *Use* was a behaviour, rather than a consequence of *Information* and *System Quality*. Although, accepting that *Intention to Use* might be a better variable in some contexts DeLone and McLean argue that in most cases usage was an appropriate measure particularly when use of the tool is voluntary (DeLone and McLean, 2003).

The DST Performance Measurement Model uses the variable of *Use* rather than *Intention to Use.* Although *Intention to Use* was found to have a higher strength of connection, Petter and McLean (2009) still identified there to be a relationship between *Use* and the other categories. The reason for the choice of *Use* was that the case study had identified that the majority of NGETs DSTs were databases and spreadsheets created and maintained by individuals working in AM roles. In this regard, it is unlikely that they would create a DST that they did not intend to use either now, or in the future. Of greater significance was whether they were actually using the tool.

Stage 2: Defining the Model Method and Subcategories

Stage 1 of creating the DST Performance Measurement Model defined the categories under which DST performance would be measured. To improve the consistency in how the model was applied within industry, the methods and subcategories to be measured made under each of the five categories were defined.

Figure 59 presents the enhanced DST Performance Measurement Model. It shows the method (validation, verification), and the subcategories measured under each of the five categories.

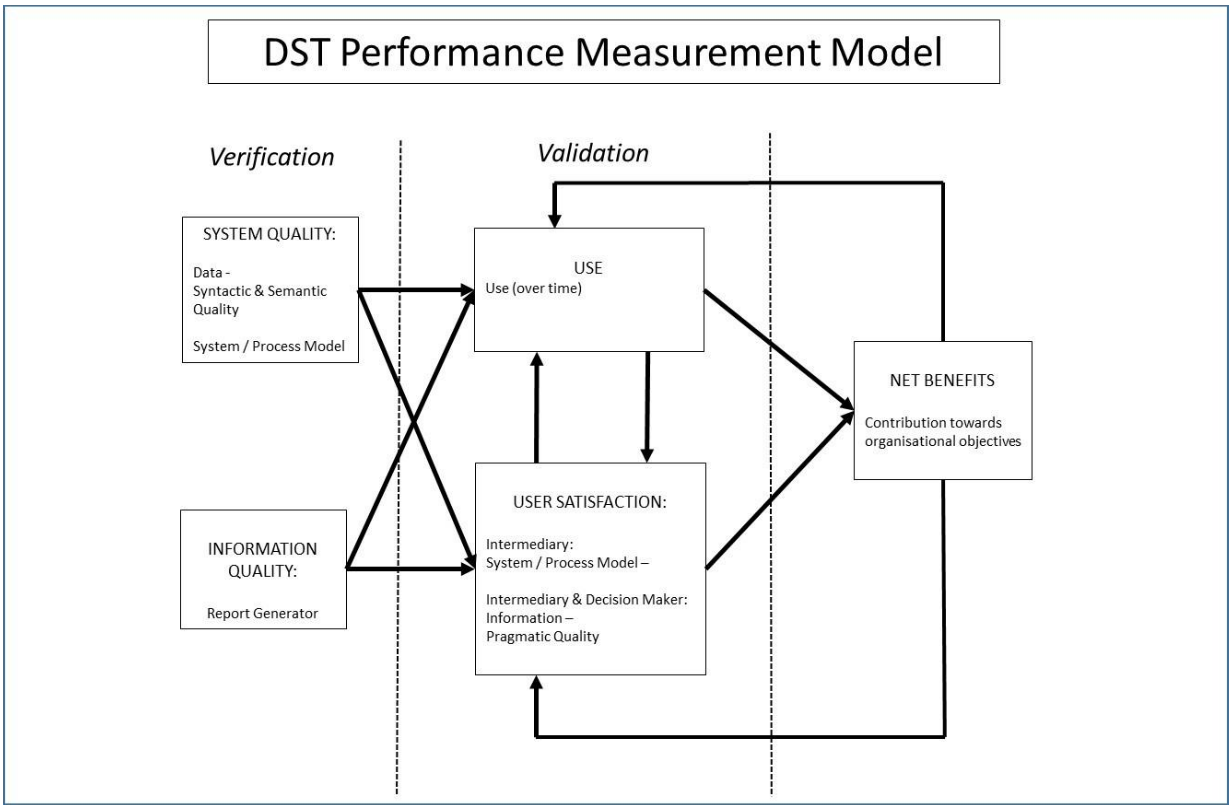


Figure 59. Stage 2: DST Performance Measurement Model

Verification and Validation

Within the field of computer science the terms *verification*, and *validation* are frequently used in connection with assessing or demonstrating performance. Under the definitions laid out in the IEEE Standard verification is "The process of evaluating a system or component to determine whether the products of a given development phase satisfy the conditions imposed at the start of that phase", validation is "the process of evaluating a system or component during or at the end of the development process to determine whether it satisfies specified requirements" (IEEE Std 6010.12 -1990 (R2002), 1990).

Given this, verification confirms that the product is built right – it conforms to specification - whereas validation confirms that the right product is being built – that it meets the stakeholder's needs. This difference means that whereas verification is a relatively simple paper exercise, whereby a system is checked for compliance against a predefined specification, validation is more complex operation that will require customer input.

As stated (8.3.2) the DeLone and McLean Model proposes that an IS system is first created. The user will experience the system. This will influence their work and result in net benefit. This would imply that measures made at the *System* and *Information Quality* stage should be a case of verification – does the DST comply with the specification. Whilst at the *Use* and *User Satisfaction* stage it is a case of validation – what is the customer's experience of the system?

Whether *Net Benefits* are assessed through verification or validation is less straightforward and is considered in detail later within this section.

DST Performance – Subcategories

The seminal work of Sprague (1980) identifies that DSS are generally considered to comprise of three components: database(s), model(s), and a report generator through which models and databases are brought together to create information. Underperformance in any of these three areas can affect overall success. Consequently, measures of performance should include each of these three components.

Within these works, it is argued that although not all DSTs are DSS, there is overlap in the components they contain. That is, DSTs will receive data, that data will be processed, and then accessed in order to gain information to support decision-making. Table 34 presents the component terms and how they are defined within the DST Performance Measurement Model.

Table 34. DST Performance - Components

COMPONENT TERM	DESCRIPTION
DATA	Data inputs to the system (includes databases and non-database sources).
SYSTEM / PROCESS MODEL	The component of the system that determines how the data will be processed.
REPORT GENERATOR	The component within the system through which the model/process and data are combined and manipulated in order to generate information.
INFORMATION	The output generated by the DST

Data and Information

The quality of information/data is a key factor when making asset decisions (Borek *et al.*, 2011; Woodall *et al.*, 2013). It is an expectation of the ISO AM Standard that it should integration with other organisational systems (BS ISO 55000 Series: 2014). The International Standard ISO 8000-8: 2015 Data Quality defines the methods to manage, measure and improve the quality of *information* and *data* (BS ISO 8000-8:2015).

Within ISO 8000-8: 2015 *data* is defined as "reinterpretable representation of information in a formalized manner suitable for communication, interpretation, or processing".

Information on the other hand is the "knowledge concerning objects, such as facts, events, things, processes, or ideas, including concepts, that within a certain context has a particular meaning" (BS ISO 8000-8:2015). Therefore, applying these definitions to this work, *data* is interpreted as being the input to the DST, whereas *information* is the output following processing of the data.

Within the ISO Data Quality Standard information and data quality is defined and measured according to three categories: syntactic, sematic, and pragmatic quality. A description of the three categories, and how the Standard recommends they are tested, is presented within Table 35. From this it can be seen that whilst syntactic, and semantic quality are measured by verification (that they conform to specification), pragmatic quality is measured by validation (that it meets the customer requirements).

Table 35. Data and information quality categories (BS ISO 8000-8:2015)

Quality Category	Description	Method
Syntactic	The degree to which the data/information conforms to its specified syntax. That is, the data aligns to the required structure format.	Verification
Semantic	The degree to which the data/information corresponds to what it represents.	Verification
Pragmatic	Conformance to basic usage-based requirements e.g. the data/information is understandable, and timely.	Validation

The DST Performance Measurement Model adopts the same approach with verification of the syntactic and sematic quality of the data under *System Quality*, and a pragmatic validation of information under *Satisfaction*.

System / Process Model

The system model is one of the three components of a DSS. Within manual systems there may be no system model, but it is argued that this is replaced by the process model. That is, to reach a solution there must be a process that is followed. Consequently, although one maybe computerised and the other manual, they are in effect the carrying out the same role.

Within the literature, different approaches have been applied to measuring the performance of system models. Whereas some authors have concentrated on representativeness – the extent to which the model fits the real system, the focus of others has been on usefulness – usability and cost (Landry *et al.*, 1983).

Borenstein (1998) claims that very few model based DSS have been *verified* “process of testing that a model has been faithful to its concept”, or *substantiated* “the demonstration that a computer model, within its domain of applicability, possessed a satisfactory range of accuracy, consistent with the intended application of the model”. Instead, much of the work focusses on *evaluation* “the process of assessing a software systems’ overall value”. This is generally considered problematic as only through verification and substantiation is it identified what a system knows, knows incorrectly, or does not know.

Within the DST Performance Measurement Model, the system/process model is both verified (*System Quality*) and validated (*User Satisfaction*).

Use

DeLone and McLean (1992) identify that a number of variables have been used to assess *Use* including: amount of use; duration of use; and amount of connection time. Therefore, *Use* can include not only the number of problems the system helps solve, but also the amount of time that is spent logged into the system. Depending on the nature of the tool, both of these measures have the potential to be either positive or negative indicators.

For example, let us consider two different DSTs.

- Tool 1 has been designed to reduce the time taken to make decisions.
- Tool 2 has been designed to improve the effectiveness of decisions that are being made.

For Tool 1 a positive performance measure would be one where the time taken to generate the report (the duration of time spent) is low. However, for Tool 2, the more appropriate measure would be occasions of use, rather than time taken to generate the report. However, even this may be simplistic as for Tool 2 time taken to generate the report will incur a cost that could negate any effectiveness gains and is therefore a consideration. Furthermore, occasions of use where the tool has been design to, but is not actually increasing effectiveness, would produce a positive result.

The complexity of this measure was identified by DeLone and McLean (2003) as part of the Model’s ten year review. They state that researchers should consider the nature, extent, quality and purpose of system use, and further warned that although a system is being used it does imply that the full functionality is being utilised. Notwithstanding the complexity that accompany measurements of *Use,* they argue that for voluntary system (such is generally they case for DST), declining usage may be an important indicator that benefits are not being realised.

User Satisfaction

The DeLone and McLean model does not define what aspect of satisfaction is being considered. Measures have included both specific and overall satisfaction, and involved both single and multiple metrics (DeLone and McLean, 1992)

As was shown in the work of Alter (1977), there are two categories of user in a decision system. The intermediary – the hands-on user who generates the information - and decisions makers – those who apply the information to decision making. Although in some cases the two are the same person, in others they may be a different individual, or multiple actors.

This aligns with the findings of the NGET case study (Chapter 5). Whereas the Network Output Measures (NOMs) DST had both intermediaries and decision makers, with the Strategic Asset Management (SAM) and Whole Life Value Framework (WLVF) these could be either the same, or different individuals. As both intermediaries and decision makers have the potential to affect Net Benefits, the satisfaction of both is measured within the DST Performance Management Model. However, although satisfaction of the model/process and information is measured for intermediaries, only the satisfaction with the information is measured for the decision makers. The reason for this was that (for a voluntary DST) if an intermediary experienced poor system quality (i.e. slow system response time) this may influence their decision of whether to use the DST in the future. Likewise, if they feel that the information quality was lacking. As a result fewer reports would be generated, resulting in less opportunity for them to be used by the decision maker. On the other hand, the decision maker has no experience of *System Quality*. Whether there is a slow response time will have no bearing on them. The influence they have on Net Benefits is determined by whether or not they use the outputs of the DST when making decisions. This behaviour will be influenced by their satisfaction with the information quality.

Although addressing the question of what components would be validated, and by which users, there remained the question of what to do in the case of multiple users i.e. multiple intermediaries or multiple decision makers. Ultimately, the question of how many users to consult will be contextual and should consider the constraints, and cost / benefit, of collecting and analysing data.

Net Benefits

The range of measures that have been used to measure benefits (DeLone and McLean, 1992). Asset Management aims to realise value that contributes towards the organisation achieving their objectives. Consequently, performance measures should independently, or in combination, provide a measure of the value of the asset that links directly to achievement of organisational objectives. That is to say, the measures of *Net Benefit* should align to the organisational objectives.

However, it is unlikely that a DST could or should deliver value across all of the objectives. For example, NGETs organisational objectives include an ambition to increase workforce diversity (Table 16), it is unlikely that the purpose of a DST used within AM would be to deliver against this specific objective. This would imply that value should consider not only alignment with organisational objectives, but also the purpose of the tool.

However, there is a complication is adopting this approach. By evaluating the DST against its specified intended purpose, there is the potential that unforeseen consequential benefit (or disbenefit) are missed. For example, NGET have strategic objectives of both increasing operational performance and reducing greenhouse gas emissions (Table 16). In the course of their business NGET might decide to implement a DST aimed at improving the effectiveness of decisions about when to replace overhead cables. The DST they create replaces the need for site visits and as a result operational performance gains are made. However, a consequential benefit of less site visits is less transport emissions. Although this benefit was unintended, it contributes towards NGET achieving its organisational objectives. If evaluation against intended benefit was used this consequential benefit may not be identified.

The model proposes that when measuring *Net Benefits* it should be a case of evaluating the DSTs overall value against all organisational objectives. In this way, the tool is not only assessed against its intended benefits, but any consequential benefits / disbenefits it creates. This holistic approach aligns with the AM paradigm (2.1.1).

8.4 Chapter 8 – Summary Points

Technique 1 - Creating a DST register:

- Registers are commonly used as a means through which to hold information about assets.
- The information contained within a register is contextual and can extend to information that is used in identification, operational management, and accounting.
- Within the DST Performance Management Process the register is used to both identify and record performance management information.
- Within the register defined DST Type categories aims to create a common understanding across AM and IS departments.

Technique 2 - Applying a criticality rating:

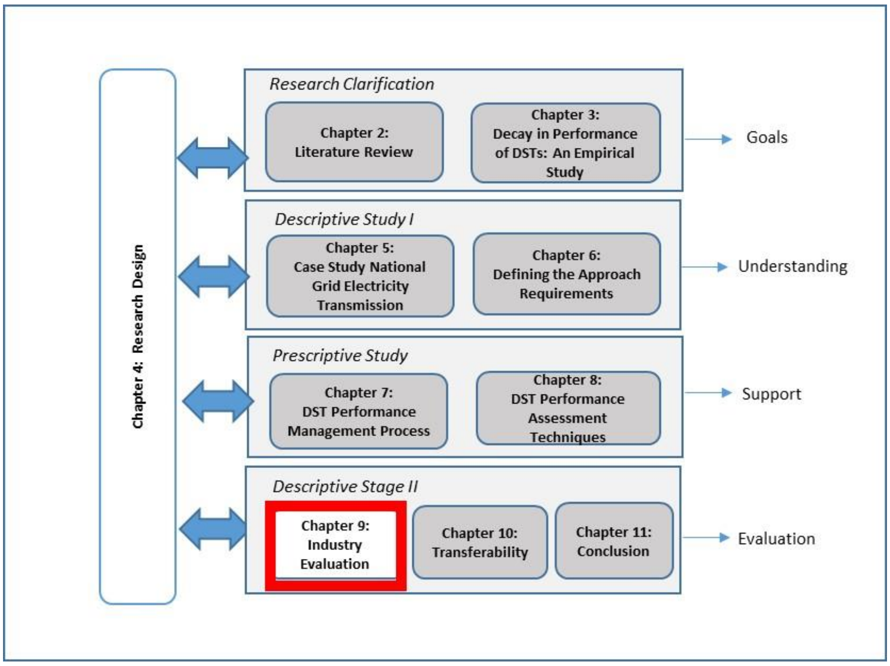
- Identification of critical assets is commonly seen within AM.
- Methods of critical asset analysis seen within the literature include qualitative, AHP, and Risk Assessment Techniques.
- Risk assessment techniques focus on the probability and consequences of a risk event occurring.
- Within the UK electricity transmission sector they are required to report on the health and criticality of network to the UK regulator, Ofgem.
- Within Ofgem reporting a two-stage approach is used. First, the critical assets are identified. Annually, a criticality analysis (probability and consequences of a risk event occurring) is undertaken in order to identify the replacement priorities.
- Within the DST Performance Management Process the critical rating should be assessed against the actual or potential value the DSTs contributes towards achieving the organisational objectives.

Technique 3 - Measuring DST performance:

- There is no accepted approach through which to measure DST performance.
- The Delone and McLean Model of IS Success had been extensively validated for use in measuring IS system performance.
- The model proposed for measuring DST performance is based on an adapted version of the Delone and McLean Model.
- The DST Performance Measurement Model includes both verification (it conforms to specification) and validation (that it meets the customer's needs).

In combination, Chapter 7 and 8 define an approach for managing DST performance. Within Chapter 9, an industry evaluation of the approach is presented.

Chapter 9: Industry Evaluation



The aim of the research conducted within this PhD was to create a conceptual approach to manage the performance of decision support tools used within an Asset Management context. Key to its progression from conceptual to experimental stage of research was that it was considered both logical and usable by industry.

For this research, a focus group of NGET subject matter experts was used as a means of evaluating the proposed conceptual approach. Within this Chapter, the evaluation approach is detailed (9.1). Following, the results are presented and discussed (9.2 - 9.3). Finally, the key findings arising from this study are summarised (9.4).

9.1 Industry Evaluation Approach

Blessing and Chakrabarti (2009) identify that often academic research fails to evaluate whether the outputs meet the goals and needs of industry. The applied nature of this research, and the requirements for industry support necessary to progress the approach past the experimental stage, meant undertaking an industry evaluation of the approach was vital.

Within the Research Design, the five-stage evaluation plan was presented (Figure 19). The research presented within this Chapter represents Evaluation 4.

Industry evaluation was conducted by way of a focus group involving five NGET subject matter experts. Focus groups had been used during two of the previous evaluation activities (Evaluation 2 & 3) and had proved to be advantageous in allowing people to explore their views; which is less easy to do in a one-to-one setting. The participants were selected by NGET to represent a cross-section of job functions and skills sets. The details of the participants are provided in Table 36.

Table 36. Focus group participant details

	Department	Job Title	Responsibilities in relation to DSTs
Participant 1	Asset Policy	Asset Management Development Engineer	Manager of DST users (including tools used within regulatory reporting)
Participant 2	ETO – Process and Enablement	Information Quality Manager	Assurance of asset data. Governance of asset data and information
Participant 3	Asset Policy	Asset Management Development Engineer	FMEA (failure risk effect analysis) and risk modelling
Participant 4	Asset Policy	Asset Management Development Engineer	DST modeller
Participant 5	Asset Policy	Asset Management Development Engineer	Asset risk modeller

The focus group lasted approximately two hours during which a systematic, qualitative evaluation of the research challenge, approach requirements, and the DST Performance Management Process and DST Assessment Techniques was conducted. In detail, the evaluation considered:

- Whether the experts felt that a research challenge existed.
- Whether the outputs generated in defining the approach requirements were valid.
- Whether the proposed conceptual DST Performance Management Process and DST Performance Assessment Techniques were logical and usable within the NGET context.
- Strengths, weakness, opportunities, and threats of the DST performance management approach.

The agenda and the questions posed under each item is presented within Table 37.

Table 37. Evaluation focus group agenda

	Item	Description	Led By	Purpose	Question
1	Introduction	Aim, timings Completion of informed consent	NGET Facilitator NGET Facilitator		
2	Project Background	Explain the context for the research i.e. timings, funding, research gap, outputs Discussion & capture feedback	Researcher NGET Facilitator	Validate existence of research challenge within NGET	1. Do you agree that managing the performance of DST used within asset management is a challenge?
3	Approach Requirements	Explain how the approach requirements were defined Discussion & capture feedback	Researcher NGET Facilitator	Validate the requirements which have been used to inform the creation of the support	2. The researcher has shown the stakeholder diagram used to identify the process stakeholders. 2a. Are there any identified stakeholders who should not be included? 2b. Are there any stakeholders who have been missed? 3. The researcher has shown the list of stakeholder requirements which have been captured. 3a. Are there any stakeholder requirements which should not be included? 3b. Are there any stakeholder requirements which have been missed? 4. The researcher has shown you the ten approach requirements. 4a. Are there any of the ten approach requirements which should not be included? 4b. Are there any approach requirements which are missing?
4	DST Performance Management Process & Techniques	Present the process and how it meets the requirements Discussion & capture feedback	Researcher NGET Facilitator	Verify that the support meets the approach requirements Validate that the support is logical and usable within NGET context Validate that the techniques are logical and usable within NGET context	5. The researcher has shown you a visualisation of the DST Performance Management Process. 5a. Does the process appear to satisfy the ten approach requirements? 5b. Does the process appear logical / usable for each of the three exemplar DST? 6. The researcher has detailed the establishing the context element methodology. Does the process appear logical / usable for each of the three exemplar DST? 7. The researcher has detailed the methodology for creating a DST register. Does the methodology appear usable for each of the three exemplar DST? 8. The researcher has detailed the methodology for identifying the critical DST. Does the process appear logical / usable for each of the three exemplar DST? 9. The researcher has detailed the methodology for identifying the DST where performance will be measured. Does the process appear logical / usable for each of the three exemplar DST? 10. The researcher has detailed the methodology for measuring the performance of DST. Does the process appear logical / usable for each of the three exemplar DST?
5	SWOT	Discussion amongst the group and completion of SWOT (strengths, weaknesses, opportunities and threats) analysis	NGET Facilitator	Evaluate the support	SWOT Analysis

The agenda shows that tasks were split between a NGET facilitator and the researcher. The role of the researcher was to present the research and to answer any questions from the group. The NGET facilitator ran the meeting, facilitated the discussions, and was responsible for capturing the comments on a flipchart. The reasoning for this approach was to mitigate potential biases which may have been introduced by the researcher collating comments. In order to capture the specifics of what was discussed, the focus group was also audio recorded.

Item 1 provided the participants with the context for the focus group.

Item 2 provided the participants with the project context and validated whether a research challenge exists.

Item 3 validated the research conducted when defining the approach requirements. Evaluating the approach requirements was critical as they provided key understanding used to inform the design of the DST Performance Management Process and DST Performance Assessment Techniques.

Item 4 verified that the DST Performance Management Process met the approach requirements, and validated that the Process and Techniques were logical and usable within the NGET context.

The case study (Chapter 5) identified that within NGET a range of manual, computer based database / spreadsheets reports, and customised computerised DSTs were used. The questions asked during this study evaluated the DST Performance Management Process and DST Performance Assessment Techniques across example DSTs that represented the range of types:

- The Whole Life Value Framework (WLVF) – Manual
- Network Output Measures (NOMs) – computer based database / spreadsheet report
- Strategic Asset Management (SAMs) – customised computerised system

Full details of the three DSTs are presented within the case study (Chapter 5, 5.3).

Item 5 undertakes a SWOT analysis. A SWOT analysis is a strategic asset planning technique that is widely used by Governments, academics and industry. The use of the technique within this focus group was as a means of generating insight into the strengths, weakness, opportunities and threats to the approach.

9.2 Industry Evaluation: Results & Discussion

During the focus group, responses to the questions were captured on a flipchart by the NGET facilitator. Although a useful overview, it failed to capture the depth of discussion that took place. In presenting the results first, the flipchart comments are detailed (Table 38). Following, the evaluation feedback is discussed with the benefit of excerpts extracted from the audio recording.

Table 38. Evaluation focus group. Written responses

	Agenda Item 2: Project Background
1.	**The researcher has detailed the research challenge that has been identified. Do you agree that managing the performance of DST used within asset management is a challenge?**
Response	*Define performance can be different where you sit within the business.* *Question of fitness for purpose* *Challenge of applicability of results when compare against the business model*
	Agenda Item 3: Approach Requirements
2.	**The researcher has shown the stakeholder diagram used to identify the process stakeholders.**
2a.	**Are there any identified stakeholders who should not be included?**
Response	✓ (Note: By ticking in response to the question the group were confirming that there were no stakeholders who should not be included)
2b.	**Are there any stakeholders who have been missed?**
Response	*Competitors? was considered but declined*
3.	**The researcher has shown the list of stakeholder requirements which have been captured.**
3a.	**Are there any stakeholder requirements which should not be included?**
Response	*No all ok.*
3b.	**Are there any stakeholder requirements which have been missed?**
Response	*User interface "ease of use".* *Ability to change / adapt functionality*
4.	**The researcher has shown you the ten approach requirements.**
4a.	**Are there any of the ten approach requirements which should not be included?**
Response	*(no response recorded)*
4b.	**Are there any approach requirements which are missing?**
Response	*Break up monitoring from continual improvement* *Training* *Optimisation (perhaps a function)* *The way you manage DST should reflect regulatory context*
	Agenda Item 4: DST Performance Management Process & Techniques
5.	**The researcher has shown you a visualisation of the DST Performance Management Process.**
5a.	**Does the process appear to satisfy the ten approach requirements?**
Response	*Yes*
5b.	**Does the process appear logical / usable for each of the three exemplar DST?**
Response	*Yes*
6.	**The researcher has detailed the establishing the context element methodology.** **Does the process appear logical / usable for each of the three exemplar DST?**
Response	*Yes*
7.	**The researcher has detailed the methodology for creating a DST register. Does the methodology appear usable for each of the three exemplar DST?**
Response	*Yes*
8.	**The researcher has detailed the methodology for identifying the critical DST. Does the process appear logical / usable for each of the three exemplar DST?**
Response	*Yes* *Consider our criticality categories*
9.	**The researcher has detailed the methodology for identifying the DST where performance will be measured. Does the process appear logical / usable for each of the three exemplar DST?**
Response	*Yes*

10.	**The researcher has detailed the methodology for measuring the performance of DST. Does the process appear logical / usable for each of the three exemplar DST?**
Response	*Suggest a division of the satisfaction box* *Splitting box because satisfaction of user & model may not achieve holistic satisfaction hence separation (see adjusted diagram)*
11.	**The researcher has detailed the treatment element methodology. Does the process appear logical / usable for each of the three exemplar DST?**
Response	*Yes*
	Agenda Item 5: SWOT
	Compared to the current situation within NGET what are the strengths, weakness, opportunities and threats of implementing the process
Strengths	*Better quality AM approach* *Best practice – demonstrate maturity* *Alignment criticalities business objectives* *Alignment criticalities to business drivers* *Life-cycle approach* *Transparency of DST including value* *Proactive DST mgt rather than reactive* *Creates visibility of DST in use*
Weaknesses	*Effort and time* *Subjective and high risk* *If tools are non critical could be a waste of effort* *Articulate value of delivering this and clear understanding of the value of the DST*
Opportunities	*Align criticality & business criticality* *Align DST & business outcome* *User experience captured / improved* *Reduce business risk* *Greater uptake of existing DST around the business and delivered value creation* *We get in first and shape the approach*
Threats	*We may not like what we find* *What is the value of understanding the process* *Understanding needs case* *We will be able to explain value business case* *Length of adoption* *Ridged process difficult to articulate value e.g. moving from our existing approach* *Others get in before us and tell us what to do*

9.2.1 Research Challenge

Question 1 aimed to validate that a research challenge existed. That is, to understand whether within NGET subject matter experts there was a perception that managing the performance of DSTs was a challenge.

The term 'performance' is one of the common terms and common definitions for ISO management system standards given in Annex SL of the Consolidated ISO Supplement to the ISO/IEC Directives, Part 1 (BS EN ISO 9000: 2015). Within The International Organization for Standardization 'performance' is defined as a 'measurable result'. In the context of the ISO AM Standard 'measurable result' is in relation to an asset's ability to fulfil requirements or objectives.

Despite the existence of the ISO definition, the group considered the term ambiguous and perhaps misleading.

"I have a question. Is it the correct word to use performance because…performance means this tool [pen] is mine for writing whether it is writing or not…that is the performance isn't it?"

There was a strong perception amongst the group that 'performance' would be interpreted differently within the business.

"if you talk to the people who build the tools they'll tell you it's working. It's performing well. Whereas the actual user, or the person who wants the output is sat there thinking that's a pile of…"

"there will be different perceptions of performance"

This reflects what was seen within the empirical study (Chapter 3), where there was different interpretation of the question by the participants. The focus group considered that perhaps it was not DST 'performance' that was a challenge, but 'fitness for purpose'.

"if we put the data that we have now into [DST name] it generates valid answers. It's a question of whether they actually match our business objectives…a lot of the tools we have used before, they sort of work but they are not appropriate because the business has different output measures or there are different priorities so there is nothing wrong with the DSTs, it is fitness for purpose, rather than its performance".

9.2.2 Approach Requirements

Questions 2 – 4 systematically addressed the steps taken to define the approach requirements. There was discussion within the focus group as to whether the five stakeholders identified (customers, owners, government, employees, and suppliers) should be expanded:

"*The only one which possibly springs to mind is competitors…I would sort of put a dotted red line around it."*

"land and development would talk about activist groups"

"if the DST is balancing the work force requirements in the future then the unions might come in"

"someone in the treasury would include financial community because they are about raising money for the business"

The group concluded that there were tiers of stakeholders. All stakeholder groups on the Freeman (1984) model would probably be involved. However, the five that were identified represented the core.

Validation of the stakeholder requirements concluded that there were none identified which should not be included. It also demonstrates that identifying the requirements for a system is not straightforward. There was a challenge in understanding what the 'voice of the customer' meant and consequently whether 'new' requirements were indeed new, or variations on those previously seen.

"'Can be upgraded' is just about forward fitting…well that's what it sounds like to me whereas 'agile' is about repurposing?"

"Is there something about ease of use or ease of accessibility…something about how easy it is to log on to the system"

The thematic analysis approach taken to identify the key concepts within the ISO AM Standard, and then to map the stakeholder requirements to key concepts (Chapter 6), was systematic and transparent. However, there are no specific requirements for a DST performance management process within the ISO Standard, and as identified, there is still debate amongst the practitioner community as to how terms used within the standards might be interpreted (Chapter 6, 6.3.2). The resulting ten approach requirements were therefore necessarily constructed, and subject to interpretation.

When taking part in the focus group the participants were not given access to the analysis undertaken to identify the key concepts (Table 24), or how the NGET expert had mapped the stakeholder requirements to the key concepts (Table 26). When asked to validate the approach requirements this appears to have generated discussions around the naming and scope of requirements i.e. whether monitoring and continual improvement should be broken down into two individual requirements, and whether there should be a separate requirement for 'regulatory compliance' or whether that was covered within the scope of contextual?

"I might break the monitoring and continual improvement up"

"*That would be covered by your contextual. It just depends on where you are operating the system. Whether it would be a regulated industry or a non-regulated industry. Or what part of the world you are doing it"*

9.2.3 DST Performance Management Process

Despite the ambiguity of the approach requirements, they freely reached a consensus that the process met the requirements (question 5a). At the point at which this question was posed the full DST Management Process and Performance Assessment Techniques had been presented to them. This would suggest that the act of presenting the approach may have changed the environment; shaping their perception of what each of the approach requirements might mean and therefore what it would take to meet that requirement.

When asked whether the process appeared logical / usable for the three example DSTs (question 5b) the group agreed.

"I think all three of them are ok."

"I can't think of any examples where it doesn't work. So it does appear logical."

When looking in detail at the process, the focus group agreed that the *Establishing the context* element of the process appeared logical/usable for each of the exemplar DSTs (question 6).

They also agreed that the methodology for creating the DST register appeared logical and usable for each of the three example DSTs (question 7). However, there was a need to modify the DST Type I categories.

The Type I categories of manual, computer based database / spreadsheets reports, and customised computerised systems, had been constructed based on the literature. However, the focus group considered that there was a forth type of *configured computer systems*.

"generally we talk about customisation and configuration. And generally we would say that we configure things because customising is an element of bespoking… whereas, configuration means that you won't have changed the software but you have configured it to fit your user cases or scenarios…, but the core code is the core code".

There was a need to differentiate between customised and configured systems because each had different management requirements and risks.

"[customised systems] we are completely dependent on supporting those. So the management process for those needs to make sure that we keep the knowledge and skills. Whereas if we have bought an off the shelf package, and we haven't tinkered with it, then we can refer back to the manufacturer of that for the support".

Although the group agreed that the act of applying a critical rating was logical and usable (question 8), they raised that further thought was required to establish the critical rating category names. The case study (Chapter 5, 5.3) identified that different critical rating categories were used for different DSTs types within the business. The group identified that additionally there were critical ratings used in reporting for data.

"for a data perspective we follow the business continuity categories which are operationally critical, critical, core, and efficiency and performance" and that they would need to make sure the most appropriate terms were used for the context.

The group agreed that the method used to identify which DST would have its performance measured appeared logical/usable for each of the three DSTs (question 9). They also agreed that the DST Performance Measurement Model was useful (question 10) in that it focussed attention on the net benefits to the business.

"you could have a really fantastic DST which lots of people are using but is it delivering the net benefits which you expect it to? Everybody's happy with it. It's a breeze to use. You've got all the data and the model is fantastic but the satisfaction to the net benefit how strong is that link?"

There was a group consensus of the benefit to measuring user satisfaction.

"For me it is more the satisfaction element that will mean more"

"That takes me to the [DST name] where the satisfaction of actually running it, the user element, used to be painful and now we have actually done something about that"

"there will be a lot of DSTs which are used very heavily…but the satisfaction will be relatively low".

Within the focus group there was discussion concerning the causal relationships between the elements and the connections within DSTs differed from general IS systems.

"[IS system] the more you use it the higher the net benefit because in some respects you have bought a piece of software to do a specific job. So therefore there is more likelihood. Whereas with a DST I'm not sure whether there is…"

"system quality would feed into that top box and information quality would feed into that bottom one and then you would have two arrows between those two. But I don't think the information quality would support that bit"

Despite this debate, it was agreed that the categories within the model were logical.

"Where you are heading for is the right-hand box. That's the true understanding of performance. And if you are saying that for a net benefit the DST is making a massive contribution against organisational objectives. In which case you might go well everything looks rosy. If it wasn't you would be asking yourself why and then in terms of validation you could go is it because nobody is using it, or is it because the users who are using it are finding it a pain in the backside. Or is it because whilst everything is fantastic the output is not making sense or useful. And then once you have answered those you would go so why is the output not useful, and then you would say because the report generator part of it is just not delivering anything. We've got good data, we've got a consistent process but we aren't actually turning it into anything that we can understand. Or you might say that the data is fantastic but the model is flawed. Or heaven forbid the model is fantastic, the reports are fantastic but the data is a bit suspect. Yes, so I think the model works but there might be just a little bit of tweaking [with regards to the causal relationship links]".

The NGET proposed amended model is presented in Figure 60. Within the amended version:

- The User Satisfaction category is split into two separate boxes: satisfaction of the intermediary with the system model / process, and satisfaction of the intermediary and decision maker with the information quality.
- The arrows connecting the System Quality to User Satisfaction category are amended (linking system quality only to satisfaction with the model/process, not the information quality).
- The arrows connecting User Satisfaction to Net Benefit are amended (linking net benefit only to the satisfaction with the information quality, not the satisfaction with the model/process).
- Whether there was a connecting between Use with Net Benefit was considered uncertain.

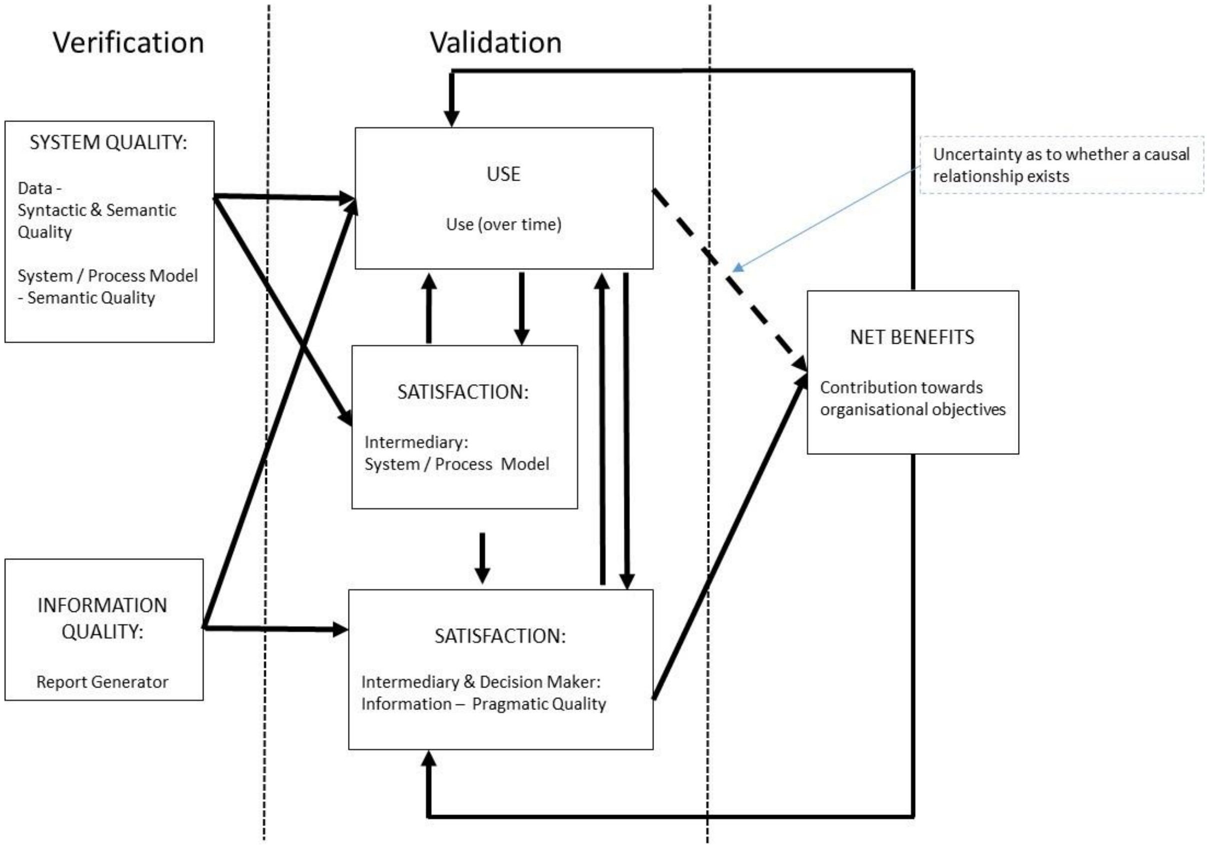


Figure 60. NGET proposed amended DST performance measurement model

In the proposed model, the satisfaction box has been split. The reason for this was:

" the satisfaction of the user and system model does not necessarily correspond to a satisfaction with the decision maker and the information. So we felt that there were two satisfaction boxes. Both of which will influence use and will influence each other, but it is only this one [information]…that will link to that [net benefits]. Because you can use it loads but if don't get satisfaction here [information] then you don't get that [net benefits]"

The group identified that although the generic application of a treatment was logical (question 11), in reality, making decisions about what treatments are applied in a particular circumstance might be difficult.

"For the legacy models sometimes the treatment will not always be that practical to be able to apply. That might be because you haven't recorded the documentation of why you did stuff the way you did it in the past. Or the models or the data sources you used. It might be difficult to apply a treatment to correct the process"

It was suggested that:

“you want to try it by going through the process…do an evaluation to determine whether treatment is available and what that treatment would be…”

9.3 SWOT Analysis

The group identified a number of strengths that centred on the approach being linked to the key concepts that underpin the AM Standard such as life cycle thinking, and linking the value of DSTs to the business objectives.

“…a set of criticality categories which are quite transparent and comparable, and linked to the core business objectives”

“the alliance of business objectives is a strength”

Adoption of the approach was seen as demonstrating mature Asset Management thinking.

“if we are trying to move towards an organisation that is following best practice. I think this would form a key part of that”

“we want to be seen as a mature, then this is at the cutting edge of thinking”

Which would encourage cross-functional knowledge sharing.

“because how many times have we seen that people are not knowing that something is already here and going out and trying to procure something, or getting people in to develop a spreadsheet”

“So if it is all in one place where you can access and see what we have got…you can go oh, I didn’t know they were doing that”

There was also an element than rather than being reactive the organisation would become proactive in its management of DSTs.

“you don’t know that your DST is not delivering the levels of value unless you have done some type of retrospective analysis and this actually puts you on the front foot”

“…forces you to be proactive about managing your DST rather than reactive. So we tend to at the moment only worry about it when we go on hold on this isn’t giving us the answers we wanted it to”

The main the negatives were seen not in the specifics of the approach, but in being able to persuade the business of the value in adopting it, and whether the introduction of a process may stifle innovative thinking.

“Articulating the actual business benefit upfront might be a bit of a business challenge”

“we would have to work around the increased Opex and explaining the business benefit”

“We are making a lot of decisions now without this. And we are adopting and improving and changing and identifying, so to actually go through the formal, rigid thinking in adopting this approach well the argument is why?”

“I think the question with this is will it actually stifle innovation. Every time that you put in a formal process there is a risk that you will stifle innovation”

Ultimately, it was recognised that by leading the research they were in a position to shape an approach which worked within AM, and the NGET organisation.

“Five or ten years from now some other people could be in the room they could hear about this wonderful approach…oh it’s now a standard, which the regulators say we have to do…so there is an opportunity that we get in first and shape the approach. There is a threat that others get in before us and tell us what to do and that we have to do it anyway but we are not shaping it”.

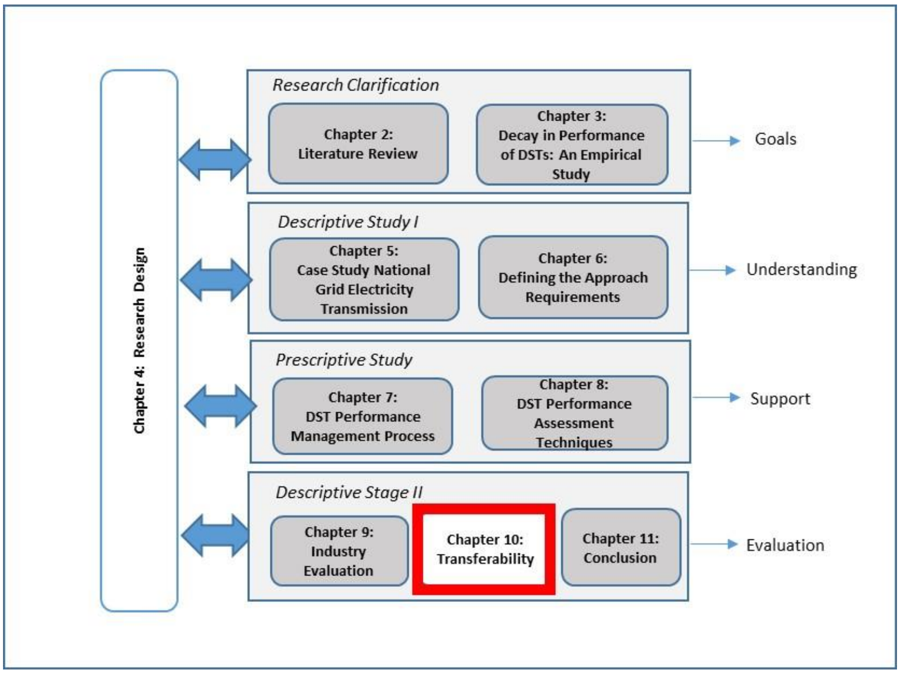
9.4 Chapter 9 – Summary Points

- Despite ‘performance’, being defined within the ISO 5500x:2014 AM Standard as the measurable result is in relation to an asset’s ability to fulfil requirements or objectives, the group considered that the term was likely to be interpreted differently within the business. They suggest that perhaps a better term would be ‘fitness for purpose’.
- The group considered that there were different tiers of stakeholders. This research had captured the ‘core’ but in theory all groups identified on the Freeman (1984) model might be considered as stakeholders.
- Terminology of stakeholder requirements and approach requirements is open to interpretation. However, the study suggests that engagement with the research may create a shared understanding.
- A forth type of Type I category of *configured computerised systems* was identified. These are different from customised systems, as they require different management regimes and have different risks associated with them.
- Within the NGET organisation, different critical rating categories are seen used across DSTs reports and for data.

- The elements of the DST Performance Measurement Model were considered valid. However, there was debate over whether the causal relationships map to those seen in the Delone and McLean IS model. The focus group proposed an amended DST performance model (Figure 60). In this model, only satisfaction with the information quality will have a causal relationship with net benefits.
- Defining a set of treatments that can be applied to each performance measurement outcome is likely to be difficult. Although the principle was agreed to ensure that a full treatment list is defined the process would need to be validated on 'real' DSTs.

The industry evaluation presented within this Chapter evaluated the conceptual approach in the context of NGET. However, the overarching research pathway intends a progression from conceptual to adoption as industry 'good' practice. For this to occur it should not only be evaluated within the context of NGET but for the transferability of the approach to the wider AM community.

Chapter 10: Transferability



Similar to the UK electricity sector, the UK water sector expect to make substantial future asset investment. For the period 2018 – 2023 estimates of £5 billion annually have been made (Water UK, 2018). Consequently, the efficiency and effectiveness of asset decisions made within this sector is of significant interest.

This Chapter presents a study undertaken to evaluate the transferability of the research to the UK water sector. First, the approach used in conducting the evaluation is provided (10.1). Following, the results are presented and discussed (10.2 - 10.5). Finally, the key findings arising from this study are summarised (10.6).

10.1 Approach Used to Evaluate Transferability

Within the Research Design, the five-stage evaluation plan was presented (Figure 19). The research presented within this Chapter represents Evaluation 5.

The transferability of the approach outside of the NGET organisation was assessed by way of a semi-structured interview with an expert practitioner from within the water sector. The expertise of the practitioner was demonstrated by way of both academic qualifications and their extensive experience. This included senior positions within asset consultancies, water utility organisations, as well as a secondment within the UK Water Services Regulatory Authority (Ofwat):

- Chartered Civil Engineer.
- Chartered member of the Institute of Water and Environmental Management.
- Affiliate of the Institute of Asset Management.
- > 25 years' experience working as a principle engineer on international infrastructure projects.
- > 6 years' experience in a Director level, asset management role, within a UK water utility.
- Experience working in a water economic regulator role within a consultancy. This included a secondment to Ofwat.

The interview, which lasted approximately four hours, focussed on four areas:

1. The research challenge:

    a. Whether the constructed relationships between literature concepts were considered valid within a water sector context (Figure 11).

    b. Whether the visualisation of the current and desired environment were considered valid within a water sector context (Figure 12).

    c. Whether within the water sector there were any existing approaches thorough which to formally manage AM DST performance.

2. Whether the approach requirements were consider valid within a water sector context (Chapter 6).

3. Whether the DST Performance Management Process and DST Performance Assessment Techniques were considered logical/usable within a water industry context.

4. Strengths, weakness, opportunities, and threats of the proposed conceptual DST performance management approach within a water sector context.

10.2 Results: Transferability of the Research Challenge

Within this research, a concept map was created as a means to construct and visualise connections within the literature (Figure 11). In conducting the research NGET had ratified these connections within the UK electricity transmission context. The question that remained was whether these connections also held within the UK water sector.

During the interview the relationships between the concepts (LR1 – LR5) were systematically evaluated. The questions and expert responses made are summarised within Table 39.

Table 39. Evaluation of the concept map (Figure 11)

	Question	Expert Response
LR1	Are DSTs used to make asset decision within the water sector?	Yes
	Does AM require taking a life cycle approach to assets?	Yes
	Does AM aim to optimise the value of assets and in doing so contribute towards achieving organisational objectives?	Yes
	Is value of an asset optimised by balancing performance, cost, opportunity and risk?	Yes
LR2	Within water sector would DSTs include manual, and computer based tools?	Yes
LR3	Does change in the environment (internal and external context) mean that DSTs need to evolve?	Yes, within the water industry this is very driven on where the regulators focus is
LR3	After a DST has been implemented do users sometimes think of ways it can be improved?	Always
LR4	Does asset management require cross-functional communication?	Yes
LR5	Are DSTs used within the water sector used for a variety of purposes?	Yes, within the water industry this included tools for how we operate our reservoirs. So how we managed the operation of our assets as well as how we managed the maintenance of our assets
	Would having a standardised classification schemes help to improve cross-functional communication?	I think it would. I think that anything which introduces a common language aids understanding. Within the water industry there can be six people sitting around the table having a conversation about the same thing, but we are actually talking about different things…we found this out when we were writing our strategy. There was terminology where people were completely at odds.

The responses did not identify any factors to bring into question the validity of the imagined relationships. The interview therefore proceeded to evaluation of visualisations of the current and desired situations (Figure 12). The responses are presented within Table 40.

Table 40. Evaluation of the current and desired research situations (Figure 12)

Validate current situation graphical representation (Figure 12, a.)	**Expert Response**
DST are being used within the water sector for optimising asset decisions?	Yes
The decisions that DSTs support relate to both what assets to acquire (Capex) and how they are managed (Opex)?	Yes. Although Opex and Capex can be a bit more fluid and can involve looking at whether Opex spend can reduce the need for Capex spend. But you do have to keep it separate because in regulatory accounting you need to report in terms of Capex and Opex.
DST can have both a positive and negative influence on optimising asset decisions?	Yes
Capex and Opex have impact investment productivity?	People think that they tell you the answer, and whole thing about rubbish in and rubbish out is just not grasped…but the other way around is if you have a very strong team who believe that they understand their assets, what they should be doing, DSSs can be manipulated to give the answer that the company thinks is right
Validate desired situation graphical representation (Figure 12, b.)	
Does managing performance of DST potentially have a positive influence on the performance of DST?	Yes
Ultimately would this potentially improve investment productivity?	Yes

Again, the responses confirmed that the water industry expert's understanding of the research challenge matched the view of the researcher, and NGET. Although demonstrating alignment in thinking this did not necessarily mean that a research challenge existed. Although there was no evidence within the literature, and no knowledge within NGET experts of approaches through which to manage DST performance, it did not mean that they did not exist. The final question asked whether the expert knew of any formal approaches to manage the performance of DSTs used within an AM environment. They confirmed that they did not.

"No, I don't. The only things which we ever did was that we had external reviews carried out of our DSTs as part of the business planning process…But it was not a formal process, it was just part of the normal audit review…they weren't seen as an asset which I think is a real problem".

Building on this questioning the researcher asked the expert to consider their experiences within the water utility and whether they would know how many DSTs they were using.

"No, I don't think they did because we would see decision support tools as [customised computerised systems] rather than tools that make decisions around tactical day to day stuff".

"*when people talk about DSTs they are talking about the all singing all dancing stuff…but actually anything that supports your decision making is a DST*".

Whether they knew which DSTs contributed the most towards achieving organisational objectives.

"The organisation thought it knew…because the organisation thought that the most important DSTs were the investment models"

Whether they knew how well they were performing.

"No. It's the closeness to how well they aligned to expectations, or how well they aligned to historic performance of assets. So they would back cast data. But it is not a formal process it's very much let's run a different set of data through it".

"The ultimate test was to put it to ops guys and say 'these models say that you should be maintaining these assets, are these assets causing you concern?' And when they all say no, then you know that there is something wrong with the model".

The expert responses demonstrated that the situation within NGET and the water sector were very similar. Within both, there was extensive use of DSTs in making asset decisions. Both undertook activities around DST control and governance however, these activities were informal and not driven by a process that formed part of the organisation's AM system.

10.3 Results: Transferability of the Approach Requirements

The approach created within this research was designed to satisfy the industry requirements as expressed by NGET. Confirmation was needed that these requirements matched those of the water sector.

The water expert was provided with the Freeman (1984) stakeholder model and asked to identify the key stakeholders. They identified there to be different levels of stakeholders. For example, the financial community and customers would "*want to know that you have it, not how it works".* In their opinion however, the stakeholders to how the approach was designed were the owners and regulators.

"…because this would be part of demonstrating that the decisions being made within the company, based on the DSTs, were as sound as they could be…owners and regulators are the ones for which the decisions are the most direct".

When asked to evaluate the stakeholder requirements identified by the NGET experts, they highlighted that they were "*really good*" but they were stakeholder requirements as voiced by someone who had a thorough understanding of asset management in terms of the ISO AM Standard.

"My Board would never have expressed any of those…well perhaps 'we know how it works'…that terminology is very much ISO…".

This insight was significant as it suggested that the maturity of asset management understanding within both the organisation and the stakeholder would influence the requirements that they voiced. This raised the question of whether if a wider range of stakeholders were included (i.e. customers and suppliers) their requirements would diverge away from recognised 'good' AM practice? Therefore, whether in evolving the approach it was a case of capturing more stakeholder voiced requirements or of explaining why the approach has been designed in a certain way, and asking whether that was logical and useable within their business and/or context.

10.4 Results: Transferability of the logic and usability of approach

The DST Performance Management Process and DST Performance Assessment Techniques were presented to the water sector expert. Following this, a series of questions aimed to assess the logic and usability of each element. The questions and the expert response are presented within Table 41.

Table 41. Evaluation of the logic and usability of the approach

DST Performance Management Process	Expert Response
The researcher has shown you a visualisation of the DST Performance Management Process. Does the process appear to satisfy the ten approach requirements?	Yes
Does it appear logical and usable within the water sector?	Yes it does
Establishing the context	**Expert Response**
The researcher has detailed the establishing the context element methodology. Does the process appear logical / useable within the context of the water utility company?	Yes, absolutely it would have worked
For manual, computer based and customised computerised systems?	It would work but I would think that people would struggle to think that way about non DSSs…the common understanding of DSTs in a lot of companies is that they are the DSSs…so [they miss out] things which are spreadsheets which I think really need to be captured
Creating a register	**Expert Response**
The researcher has detailed the methodology for creating a DST register. Does the methodology appear useable within the context of the water utility company?	You could create a register but it comes back to that cultural piece about what is a DST…You would have to have a process whereby every team leader would have to identify their DSTs…it would be a similar process to something which has been done [for data] but every day someone creates a new spreadsheet
For manual, computer based and customised computerised systems?	I think it would but it is the cultural understanding of what that all means
Identifying critical DST	**Expert Response**
The researcher has detailed the methodology for identifying the critical DST. Does the process appear logical / useable within the context of the water utility company?	Yes. However, within the water sector there are different levels of objectives…internal and external…and sometimes these are not very measurable. It is difficult to set metric for what you want your DST to achieve unless you know within your organisation what it is you want to achieve in quite a lot of detail.
For manual, computer based and customised computerised systems?	It comes back to this do people really understand that they are making decision on the basis of non DSSs that is the thing. But in principle, yes.
Measuring Performance	**Expert Response**
The researcher has detailed the methodology for measuring the performance of DSTs. Does the process appear logical / useable within the context of the water utility company?	It appears logical. I think the issue will always be around the quality of the data that feeds into the various points. Being able to identify [net benefits] is something which everyone struggles with.
For manual, computer based and customised computerised systems?	Yes, absolutely it would do.
Applying a treatment	**Expert Response**
The researcher has detailed the treatment element methodology. Does the process appear logical / useable within the context of the water utility company?	Yes, if you set your rules up properly. That's going to be a continuous improvement loop in terms of getting the process embedded. You would probably want to start with your DSS because they have the most clarity around them. Then having done that you would refine your rules across the other types of DSTs.

Analysis of these responses shows that overall the expert was satisfied that the process and techniques would work within the water sector. Of perhaps the greatest concern was that the water sector does not recognise the contribution that computer based database / spreadsheets DSTs make towards asset decision-making. This was significant as the inventory created within NGET showed not only was their use extensive, a number (~13%) were assessed at the highest critical rating level. Therefore, if they are not being recognised and formally managed, this would represent a potential business risk.

Another point of note was that the expert confirmed that within the water sector different business objectives were expressed, for different audiences. The same was found to be true within NGET whereby it was identified that there were both strategic objectives, KPIs, and metrics used for reporting to Ofgem. The challenge for an organisation would be in deciding which objectives should be used as the criteria against which the value of a DST was assessed. Although recognised to be challenging, defining the criteria would consolidate organisational understanding of which objectives the organisation prioritised.

Although the model used in measuring the performance of DSTs was considered logical and useful, concern was expressed around the quality of the data inputting into this model. This concern had not been expressed by NGET. Whether that meant that NGET had greater confidence around their data, they considered that the treatment rules could be written to accommodate data uncertainty, or if this had just not been considered was unclear.

10.5 Results: Transferability SWOT analysis

The final aspect of the evaluation was to undertake a SWOT analysis. The results are presented within Table 42.

Table 42. SWOT analysis of conceptual DST performance management approach

Compared to the current situation within the water utility what are the strengths, weakness, opportunities and threats of implementing the process.
Strengths It is a process where one does not exist. Forces assessment on what underpins decision making as an organisation.
Weaknesses Requires data which may not be available Need a link to customers for water sector (this would be that it improves decision-making and therefore improves outcomes for customer)
Opportunities Treating DSTs as an asset could change the way they're managed. Will require companies to understand vast numbers of DSTs underpinning decisions that should be controlled.
Threats Process may be seen as too onerous. Need case study – especially around rules.

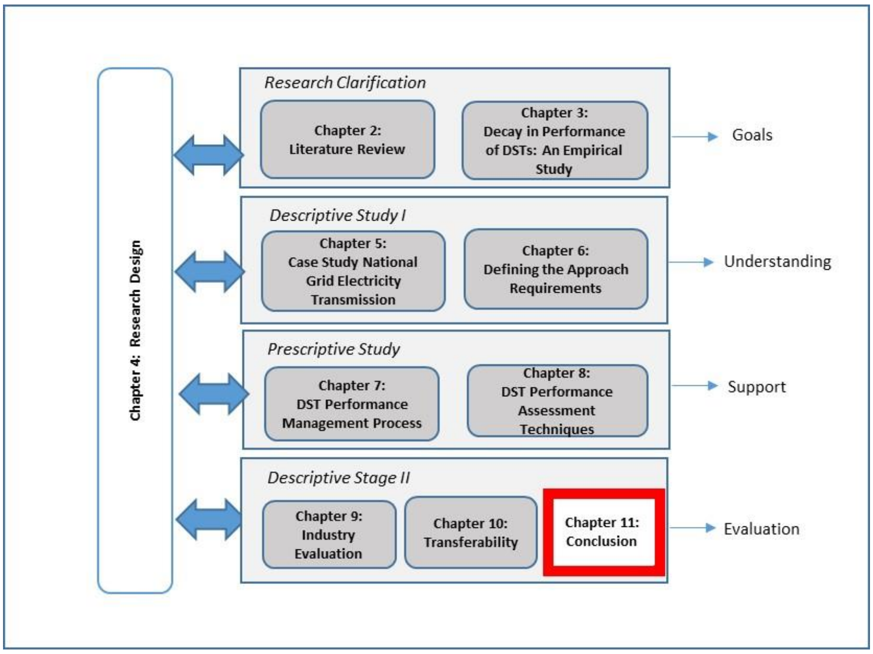
Similar to the analysis undertaken by NGET it was considered a strength/opportunity that through application of the process, businesses will be able to see the link between DSTs and decision making. However, again similar to NGET the challenge was in getting industry buy-in and the ability to demonstrate the benefits that would be derived.

As stated previously, a particular concern was that there might not be data available to populate the DST performance measurement model. Whether this is a valid concern could not be assessed without further research. Overall, the approach was given their support but recognised the need for further experimental testing.

10.6 Chapter 10 – Summary Points

- The research challenge was found to be transferable to the water sector. The key concepts constructed from analysis of the relevant literature in this area, and the proposed current and desired situations were found to be valid. It was identified that there were no know formal approaches through which to manage DST performance.
- The approach requirements identified by NGET were found valid within the water sector. However, the responses made suggested that an organisation's familiarity with the ISO AM Standard might influence the requirements expressed.
- The responses indicated that the DST Performance Management Process and DST Performance Management Techniques was both logical and useable within a water sector context. However, there would be work required in creating a shared understanding of what was considered to be a DST. Particularly, the results highlight the need to understand the criticality of end user computing (EUC) database / spreadsheets reports.
- Two areas that were identified as being potentially challenging were identifying with which set of organisational objectives the value of a DST should be assessed for criticality, and in ensuring the quality of the data that feeds the DST Performance Measurement Model.
- Similar to the responses expressed by NGET, a threat to adoption was being able to demonstrate the benefits of adoption.

Chapter 11: Conclusion



This Chapter provides a summation of the research conducted within this PhD. First, the contribution to knowledge made by this research is acknowledged (11.1). Following, a summary of the work undertaken / research findings (11.2) and a critical analysis is presented (11.3). Finally, future research opportunities are identified (11.4).

11.1 Contribution to Knowledge

Within this research it is shown that although performance management of AM DSTs is being undertaken by industry, activities are currently inconsistent and informal. Potentially, this can result in a situation where tools used to make asset decisions are not visible, and/or a risk that their performance may be sub-optimal.

The primary contribution of this research is a novel approach for the performance management of decision support tools used within an Asset Management context.

It provides a unique and structured approach for managing the risk and opportunity that accompany a change in DST performance.

In detail:

- The design of the approach is aligned to the fundamental principles of the ISO AM Standard ISO 5500x: 2014. Thus, it brings consistency between the performance management of DSTs and the management of physical assets.
- AM encompasses a wide range of organisations and sectors. The generic process design means that it can be applied across a range of businesses and business areas. Again, this improves consistency and comparability of results.
- The design of the DST Performance Management Process is based on the ISO Risk Management Process. In this way, it integrates with not only the ISO AM Standard, but the Risk Management Standard (ISO 31000:2009) and Quality Management Standard (ISO 9000:2015). Alignment and integration across Standards is a fundamental goal of The Organisation for Standardization (BS ISO 55000 Series: 2014; ISO, 2018).
- The cyclical process design ensures that the approach is not static. The approach, and how it applied within an industry setting, can adapt to reflect the evolving environment.

In arriving at the conceptual approach knowledge is created in the following areas:

1. The case study (Chapter 5), provides understanding on the use, and control and governance of DSTs within a UK Electricity Transmission business.
2. The RE study (Chapter 6), defines the requirements of an approach for managing DST performance.
3. The DST Performance Management Process applies understanding generated through the research process to define the steps for managing DST performance. This includes identifying the contextual considerations which must be made when applying the process steps.
4. The DST performance techniques (Chapter 8), applies understanding generated through the research process to define:
   The basic requirements of a DST asset register.
   An approach for rating the criticality of DSTs.
   A model for measuring the performance of DSTs.

11.2 Research Summary

The aim of the research conducted within this PhD was to create a conceptual approach to manage the performance of DSTs used within an AM context. In achieving this aim, five research objectives were defined. Figure 61 demonstrates the relationship between the five research objectives, thesis chapters, and dissemination activities undertaken.

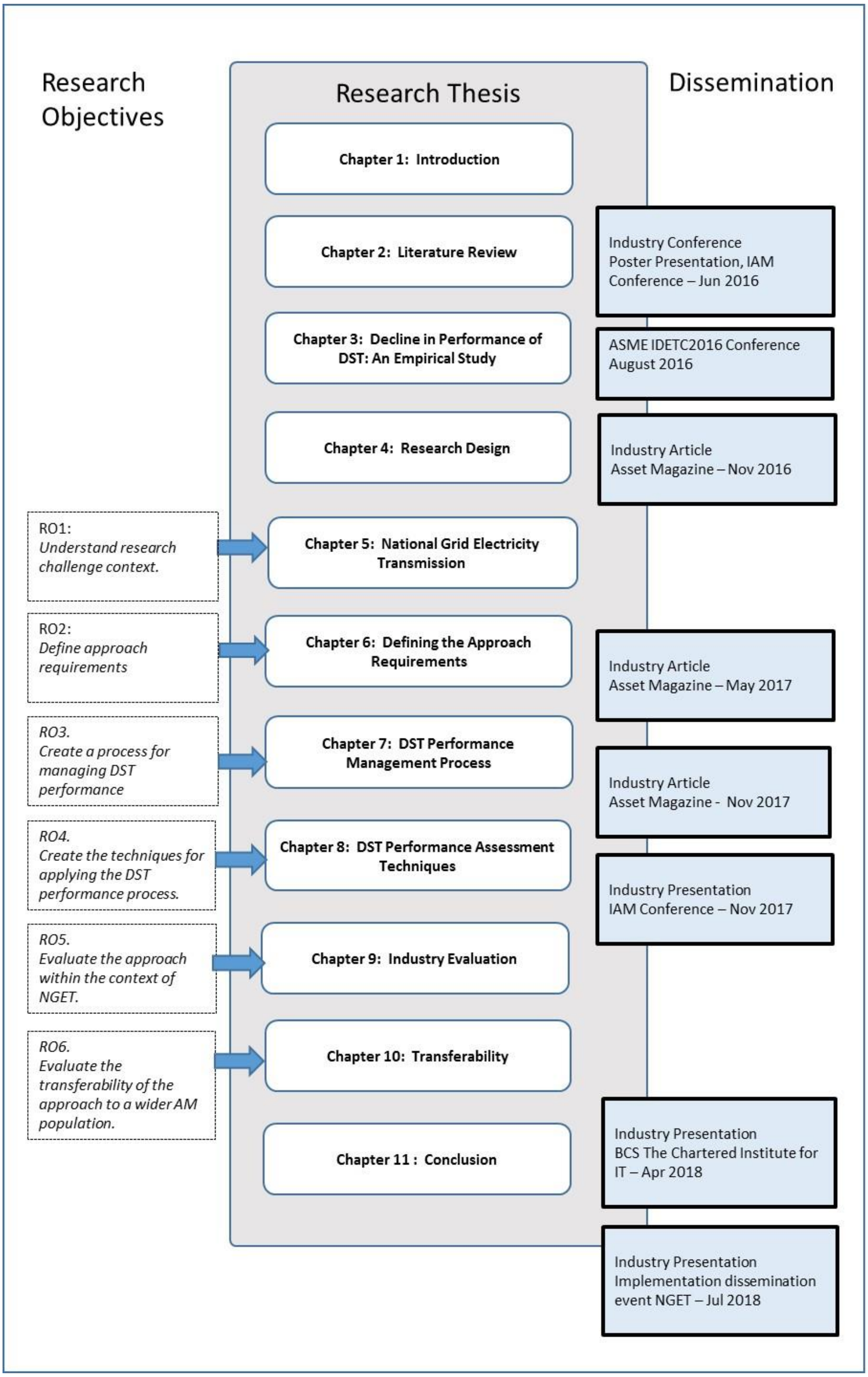


Figure 61. Research Summary

In detail, the work undertaken and findings against each objective:

RO1: ***Understand research challenge context.***

A case study of National Grid Electricity Transmission (NGET) provides understanding of how DSTs are used and governed within a major UK asset owner. The results of the case study demonstrate that both manual and computer based DSTs are extensively used to make decisions about what assets to acquire and how they should be managed. Within NGET, more than 200 DSTs were identified. Of these, ~13% were assessed at the highest critical rating level. Although governance of DSTs was undertaken, there was no coordinated process for measuring and monitoring DST performance.

RO2: ***Define approach requirements***

A requirement engineering (RE) exercise conducted within NGET identified the approach stakeholders and their requirements. The stakeholder requirements highlighted compliance with the AM Standard ISO 5500x:2014 as a constraint on the design.

Analysis of the AM Standard found there to be no specific requirements for how DST performance should be managed. However, for an approach to be acceptable, it should align with the key concepts that underpin the Standard. These key concepts were identified by way of a thematic analysis of the suite of ISO 5500x: 2014 documents (ISO 55000, 55001 & 55002).

Analysis undertaken which mapped the elicited stakeholder requirements to the key concepts resulted in the identification of ten requirements for the conceptual approach design (R1-R10).

RO3. Create a process for managing DST performance

The two outputs of the research were a DST Performance Management Process, and DST Performance Assessment Techniques.

The design of the novel DST Performance Management Process was based on the ISO Risk Management Process (BS ISO 31000: 2009). In doing so, it provided a risk-based, continually improving process for DST performance management that aligned with ISO AM Standard, and integrated and harmonised with the international Standards for risk and quality management systems.

RO4. Create the techniques for applying the DST performance process.

To improve consistency in the industrial application of the DST Performance Management Process three techniques were defined:

Creating the DST register: defines the basic information fields within a DST register. This extends to information for DST identification and operational performance management.

Applying a critical rating to a DST: Defines the technique for assessing how critical a DSTs is to the business. Criticality is based on the actual or potential value a DST contributes towards achieving organisational objectives.

Measuring DST performance: Defines the DST Performance Management model to be used in measuring DST performance. This model includes both verification of the system and information quality, validation of the use and user satisfaction with the DST, and net benefits.

RO5. Evaluate the approach within the context of NGET.

Evaluation of the conceptual approach was undertaken by way of a focus group comprising of five NGET subject matter experts.

The approach was found to be both logical and useable.

A SWOT analysis identified being linked to the ISO AM Standard as a strength of the approach. The main threat identified was not in the specifics of the approach, but in evidencing the value of adoption. Evidencing value would be necessary to secure approval for the business case enabling NGET to progress to implementation.

RO6. Evaluate the transferability of the approach to a wider AM population

A semi-structured interview with a water industry subject matter expert found that the research challenge also existed within this sector. Their evaluation found the approach to be both logical and useable within this context. Similar to the NGET an obstacle to implementation was in being able to demonstrate the benefits that might be realised through its adoption.

11.3 Critical Analysis

Although the conceptual approach was well received by industry, within an academic setting it is necessary to critically analyse the research as a means of identifying its limitations.

Evaluating quantitative research conducted in a laboratory setting is generally straightforward. Often there is only one possible ‘reality’ that can be tested by the use of recognised statistical methods. The research conducted within this PhD project was not straightforward. The applied nature, absence of empirical studies, and lack of useable quantitative data made conducting the research challenging. That said, academia cannot shy away from research of this type. In providing both their financial and non-financial support for this research National Grid demonstrate that there was an industry need, requiring academic endeavour.

The overarching goal of this research was to improve asset investment productivity. The research conducted within this PhD aims to contribute towards that goal by the creation of a novel approach to manage the performance of DSTs. The aim of the project was achieved (an approach was created). Further longitudinal operational testing is required to assess the impact of the approach on asset investment productivity.

Although it was possible to see a general widening of what might or should be considered an organisational asset, within the AM community this remains innovative rather than mainstream practice. Specifically, it is not a requirement of either the ISO AM Standard, or the regulators that DSTs should be managed in the same way as engineered assets. The challenge in undertaking this pioneering research was that businesses and practitioners have not had the opportunity to consider what their individual requirements for a DST performance management approach might be, let alone to reach a consensus across the community. Their requirements are yet to emerge and crystallise.

The use of an evolving approach aims to overcome this challenge. It provides a structured pathway from conceptual ‘prototype’, through experimental testing, to operational implementation. The scope of the research is therefore confined to creating a conceptual approach and evaluating that the approach is logical and useable.

The research identified that for NGET ensuring that the approach was compliant with the ISO 5500x:2014 AM standard was vital. However, the Standard was only created in 2014 and there is a lack of empirical validation studies to support the benefits of compliance. Notwithstanding, the Standard provides a globally recognised, continually improving platform for AM practice.

The research undertaken was largely grounded in the context and requirements of NGET. The transferability of the approach to the water sector was then evaluated. Although supporting transferability, further assessments are required across a wider sample of sectors and organisations.

11.4 Future Research Opportunities

Future research opportunities progress the research to the experimental stage. Specifically, research should be focussed in the following areas:

1. Increasing understanding on the range and extent of DSTs use within AM organisations.
2. Increasing understanding on current DST control and governance practice within AM organisations.
3. The creation of approaches through which to measure the value realised through managing DST performance.
4. Understanding the challenges in linking DST criticality to organisational objectives.
5. Experimental validation of the proposed DST Performance Measurement Model (Figure 59).
6. Experimental validation of the adapted DST Performance Measurement Model proposed by NGET (Figure 60).

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Appendix A

Physical asset decision support tools

* 1. You understand the detail given of the study and are willing to take part?

* 2. Your name

* 3. Your organisation name

* 4. Type of organisation

Asset Owner

Consultancy

Other (please specify)

5. Sector(s) in which your organisation operates

Water

Energy

Transport

Other (please specify)

* 6. Countries in which your organisation operates

* 7. Country in which you are based

* 8. Your job title

9. Responsibilities

Physical asset management - Creation (e.g. investment planning / strategy)

Physical asset management - Implementation (e.g. delivery of schemes / construction)

Physical asset management - Operations (e.g. maintenance)

Physical asset management - End of Life (e.g. bsolescence)

Physical asset management - Decision Support Tool sales

Physical asset management - Decision Support Tool development

Physical asset management - Decision Support Tool implementation

Physical asset management - Decision Support Tool operation

10. Length of time in this job role

less than 1 year

1 - 2 years

2 - 5 years

More than 5 years

* 11. Length of time at this organisation

less than 1 year

1 - 2 years

2 - 5 years

Over 5 years

12. Experience of working in/with physical asset management

Less than 1 year

1 - 2 years

2 - 5 years

More than 5 years

* 13. A50.0% After implementation the performance of tools used to support physical asset selection decays: they stop being used or the value they offer reduces.

B50.0% After implementation the performance of tools used to support physical asset selection does not decay: they continue to be used and the value they offer
remains the same or increases.

Completely Agree

Agree

Disagree

Completely Disagree

* 14. Why do you say that?

Appendix B

Name: ……………………………………………………………………………………………………….

Job Title: ……………………………………………………………………………………………………….

How would you interact with the approach: ……………………………………………………………………..

………

………

1. The approach stakeholders were identified as National Grid, NGET, private customers, business customers, NG employees working within the electricity transmission area, and Ofgem.

1A. *Are there any stakeholders identified who you feel should not be included? If so, provide detail and reasoning?*

1B. *Are there any approach stakeholders who you feel have not been identified? If so, provide detail and reasoning?*

2. The requirements of these stakeholders were identified as:

Value, safe, environmentally adhering to International Standard
Industry compliant conforms to ISO 55000 and ISO 31000
Life cycle value achieving customer requirements and over delivery of regulatory performance
Adaptable to asset base, satisfies data requirements and organisation systems
Consistent with consumer value mechanistic approach easy to understand translating inputs, process, outputs
Transparent, consistent with Scots TO's
We know how it works
Stable – repeatable and reproducible
Lifecycle management, safe, credible, economic and efficient
Performance to be agile. Accurate tool that produces validated results
Technical competence reflecting asset position and network risk
Agile can be upgraded
Delivers credible results
Safe, reliable, and efficient outputs which are understood

2A. *Are there any stakeholder requirements you feel should not be included? If so, provide the detail and reasoning?*

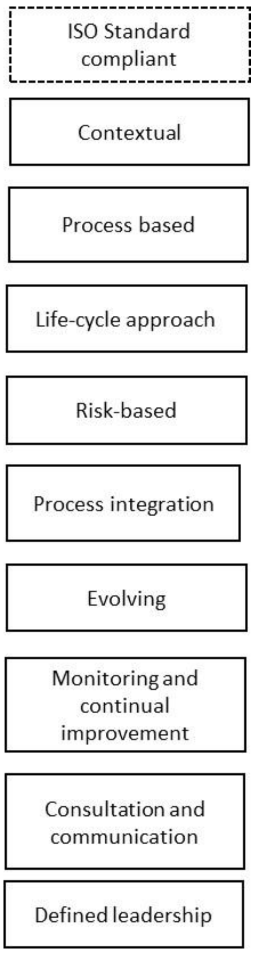
2B. *Are there any stakeholder requirements which you feel have not been identified? If so, provide the detail and reasoning?*

3. Within the stakeholder requirements it was identified that the approach should conform to ISO 55000 and ISO 31000.

3A. Do you agree with that statement? Yes / No

If 'No' provide your reasoning.

4. The fundamentals of the ISO 55000 Standard and the stakeholder requirements were analysed to create approach requirements. The ten approach requirements are:



4A. *Are there any approach requirements you feel should not be included? If so, provide the detail and justification.*

4B. *Are there any approach requirements which you feel have not been identified? If so, provide the detail and justification?*

Appendix C

Name: ……………………………………………………………………………………………………..

Job Title: ……………………………………………………………………………………………………..

Prior to completing this questionnaire the DST Performance Management Process will have been described to you by the researcher and you will have had the opportunity to ask any questions you might have.

Please respond to the following questions.

1. The DST Performance Management Process appears to address the ten approach requirements. YES / NO (if NO provide detail)

2. The logic of the process seems correct. YES / NO (if NO provide detail)

3. The process would seem workable with the context of NGET. YES / NO (if NO provide detail)